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F-111 Aircraft Fatigue Data Analysis System (AFDAS) In Service Development Progress Report Number One

K. Walker

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DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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Aeronautical and Maritime Research Laboratory

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ABSTRACT

The Aircraft Fatigue Data Analysis System (AFDAS) is a twelve channel, strain based fatigue data collection and analysis system. The RAAF have recognised that AFDAS offers significant potential improvements over fatigue meters and parametric based systems for the purpose of fatigue monitoring and structural integrity management. AFDAS has therefore been implemented on a number of aircraft types, including the F-111.

The system does, however, require further development and refinement. AMRL was requested by the RAAF to provide assistance and advice on the F-111 AFDAS installation. This report details the progress made so far on the current AMRL F-111 AFDAS support activity. The activity has included aspects which are unique to the F-111 and also some aspects which have a general applicability to the AFDAS installation on other aircraft types.

Significant progress has been made in the following areas:

a. Establishing why the strain sensor locations were chosen and how they relate to other locations of importance for fatigue or structural life monitoring reasons.

b. Eliminating operational errors and difficulties which decrease the integrity of the data.

c. Developing new data screening procedures which check the data for inconsistencies and invalid results.

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EXECUTIVE SUMMARY

Management of the structural integrity issues which arise for an ageing aircraft fleet requires a good working knowledge of the loads which cause structural damage. An effective way to obtain this knowledge is to monitor in-flight strain readings directly at the point of interest. The Aircraft Fatigue Data Analysis System (AFDAS) provides the mechanism to do just that.

AFDAS has been installed on approximately half of the RAAF F-111 fleet. An activity within the current AMRL F-111 structural integrity task is to provide support for the development and improvement of the F-111 application. The work performed on this activity at AMRL has also resulted in benefits for the AFDAS installations on other aircraft types because there are many common aspects.

This report details the progress achieved so far on the current AMRL F-111 AFDAS support activity.

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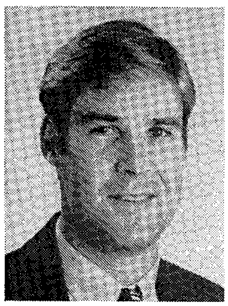

Mr Walker graduated in 1983 with a Bachelor of Aeronautical Engineering (with distinction) from RMIT. He then served for eight years with the RAAF, including a posting to the USA where he gained a Masters of Science in Aeronautics and Astronautics from Purdue University. He then worked for three years in private industry before joining AMRL in early 1994. His work at AMRL has included fatigue and damage tolerance analysis studies and aircraft load spectrum determination using the Aircraft Fatigue Data Analysis System (AFDAS). He is currently also task manager for "Analysis and Validation of Design Procedures for Bonded Repairs."

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1. Introduction

The Aircraft Fatigue Data Analysis System (AFDAS) is a strain based fatigue data collection and analysis system. The system consists of a central processor and recorder (Strain Range Pair Counter, SRPC) and strain gauge sensors placed at fatigue critical locations on the structure. The current version of the system (Mark III) records data from 11 strain channels and one C.G. vertical acceleration channel. The sensor signals are processed according to a range-mean-pair counting algorithm and the counts are stored in a 120 cell array called a range-mean-pair table.

Rather than storing the strain information as a direct time based history, the AFDAS system processes the sensor signals in real time and quantises the peaks and troughs into pre-defined levels or bands. The peaks and troughs are matched according to a range-mean-pair counting algorithm and are stored on a flight-by-flight basis as counts or occurrences of a particular peak/trough (or mean/amplitude) combination. Reference 1 describes the concept of the system in more detail.

The RAAF have recognised the potential benefits of the AFDAS system in providing an accurate and comprehensive source of data for fatigue monitoring purposes. Recording strains directly at the point of interest is seen as a significant improvement on fatigue meter and parametric based techniques. AFDAS has been implemented on a number of RAAF aircraft types including F/A-18, PC-9, Macchi and F-111.

The application of AFDAS to the F-111 was initiated in the early 1980s. The installation consists of four strain gauges fitted to each wing, seven fuselage gauges and one C.G. vertical acceleration sensor. Both wings are modified, but only the left wing gauges are normally connected. The equivalent gauges in the right wing can be connected in the event of gauge failure. The system is to be installed on eleven F-111 aircraft, and the gauges are to be installed on all wings to allow for wing movements during maintenance. The current status is that the modification has been incorporated on seven aircraft, one aircraft is being modified and another three are to be modified.

The aircraft which have been modified and are in active service are now producing data. The data is transferred to disk once a month each aircraft, and is then forwarded to the RAAF Aircraft Structural Integrity (ASI) Section at Headquarters Logistics Command (HQLC) and to DSTO Aeronautical and Maritime Research Laboratory (AMRL) for analysis and advice. The results so far have indicated some problems with the data quality and integrity. Further analysis and development is required to advance the status of the system to the point where it provides consistent, usable and relevant data to assist in the structural life management process.

RAAF engineers at ASI recently recognised that technical assistance was required from AMRL to develop the AFDAS system from a theoretical system to a mature, on-line, operational structural integrity management aid. Specific areas of concern were raised by the RAAF and documented following the Reference 2 meeting. As a starting point for AMRL, goals were identified as follows:

a. Short term goals:

(1) Review strain ranges currently in use,

(2) Establish a configuration trace for AFDAS locations,

(3) Review transfer functions for wing locations, and

(4) Investigate and advise on transfer functions in general.

b. Medium term goals:

(1) Identify readily implemented uses of AFDAS.

c. Long term goals:

(1) Provide advice on sensor calibration, and

(2) Perform a strain survey if required.

An AMRL review of these goals was conducted so that a more detailed and specific project plan could be created. The goals as stated imply that they can be addressed independently and sequentially, but this is not the case. Specific points identified for consideration in developing the project plan were as follows:

a. The suggested short term goals are inter-related.

b. Since the current operational data exhibited data quality and integrity problems, a task to co-ordinate the operational aspects was required.

c. The potential of the AFDAS system to incorporate an inter channel correlation procedure (Reference 3) was identified and a task to develop this potential was included in the plan.

d. A static wing test and strain survey to be conducted at AMRL could be used to assist with the strain range and transfer function work. Therefore, a task was included to identify suitable strain gauge locations for the test wing.

e. The issue of transfer functions had been examined previously by AMRL (Reference 2). Very limited information was available from strain surveys, and AMRL opinion at the time was that the development of transfer functions to relate AFDAS strains to strains/stresses at other significant structural locations was not practical. This activity was therefore not included as a specific task at this stage. The results from other areas such as the strain survey, configuration trace and strain range review may however lead to a specific transfer function activity to be included in a later issue of the plan.

A project plan, shown at Figure 1, was developed and incorporated in the AMRL F-111 Structural Integrity Task. The plan was presented to and accepted by RAAF HQLC ASI staff in May 1994.

This report details the progress achieved so far in the current AMRL F-111 AFDAS support activity, and constitutes the first progress report.

2. Review of Gauge Locations

A review of AFDAS gauge locations was performed for the following reasons:

a. to determine why the locations were initially selected, and

b. to assist in defining the role of AFDAS as, for example, a loads monitoring system and/or a system to monitor specific fatigue critical locations.

The general locations of the AFDAS gauges are detailed in Figure 2. The AFDAS gauge installation consists of a single uni-axial gauge at each location. These locations have evolved over many years. The F-111 was originally designed as a safe life aircraft, and through a combination of fatigue testing, analysis and in service experience, fatigue critical locations were identified to be used as life monitoring "control points". These points became known as the Service Life Monitoring Program (SLMP) control points. The SLMP was developed by the manufacturer (General Dynamics now Lockheed Fort Worth Company, LFWC) in the late 1970s, and was based on the safe life approach. The subsequent application in the early 1980s of the Durability and Damage Tolerance Analysis (DADTA) approach to the F-111 introduced many new analysis points and these became known as DADTA control points or DADTA Items (DIs). The DADTA program was also developed by the manufacturer, General Dynamics. The USAF and the RAAF accepted first the SLMP, and subsequently the DADTA, as the basis for structural integrity management of their fleets.

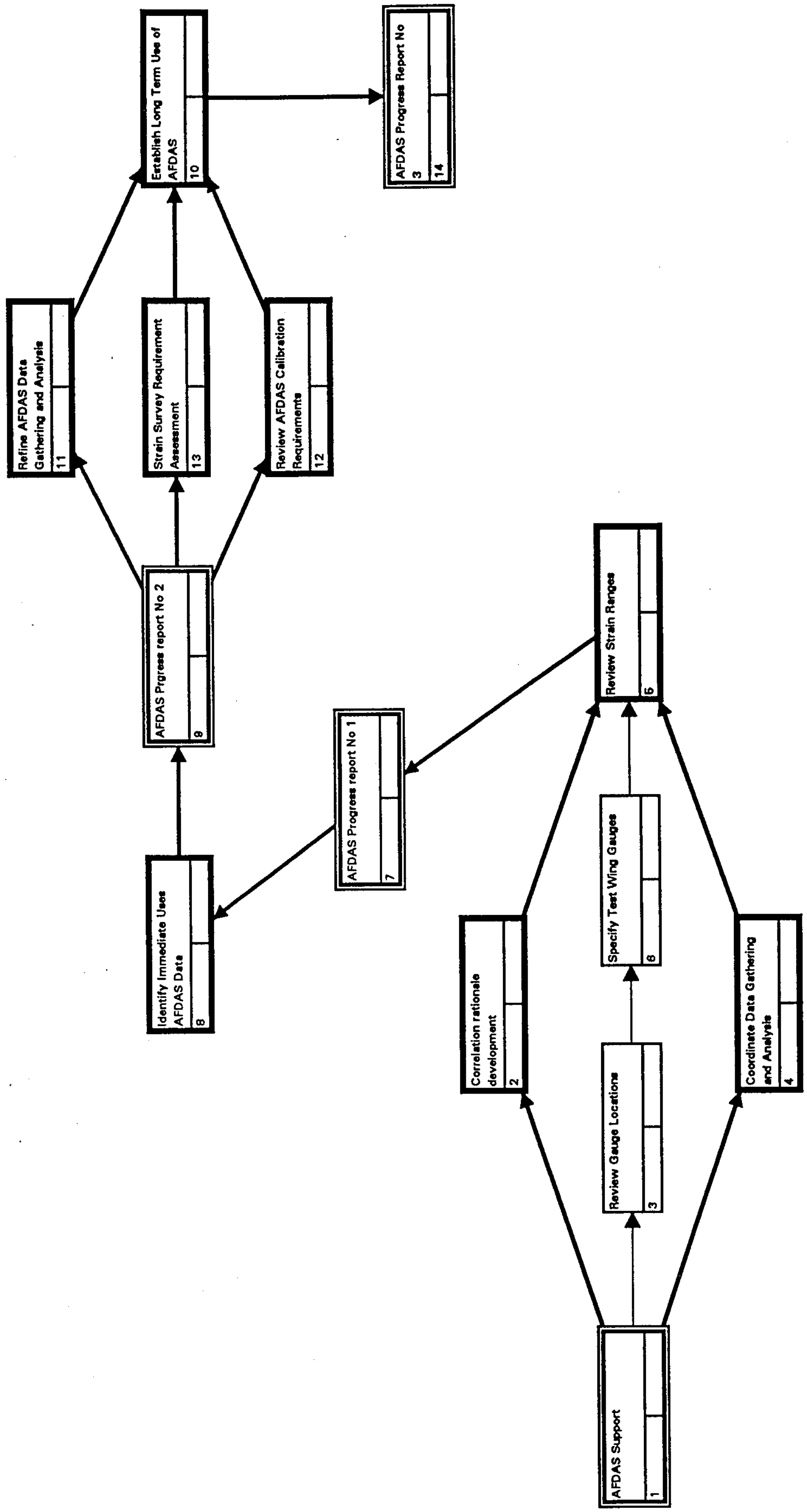


Figure 1: F111 AFDAS Support Project Plan

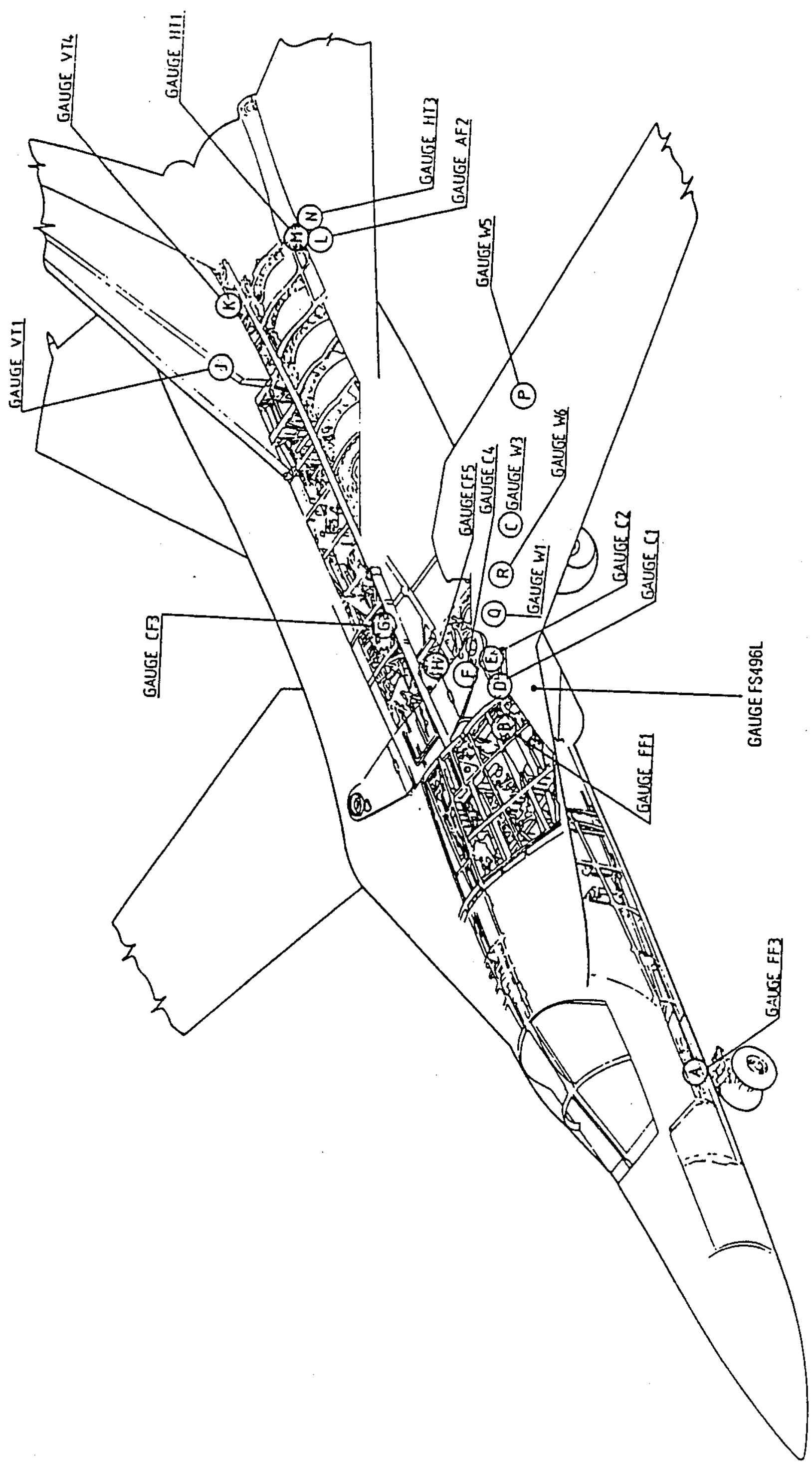


Figure 2: Approximate Locations of F-111 AFDAS Strain Gauges

There is a degree of commonality between the old SLMP control points and the DADTA Items. The AFDAS gauge locations were based on SLMP control points, some of which later became DADTA Items or are close to DADTA Items. The table below details the relationship between the AFDAS locations and equivalent/nearby DADTA locations. Annex A summarises and compares the AFDAS gauge locations with the relevant SLMP control points and DADTA Items. The diagrams in Annex A have been extracted from References 4, 5 and 6.

AFDAS Gauge Location	Channel #	Equivalent DADTA Item Location	Nearby DADTA Item Location
W1	0	86	
W3	1		87,87a
W5	2	73	
C1	3	136	159, 159a
C2	4	26, 26a	27, 29
FF1	5		
W6	6	92a	
VT4	7		41b
CF3	8	19	19a,19c,20,20a,21
CF5	9		24a
AF2	10	36	37a
Nz	11		

Notes:

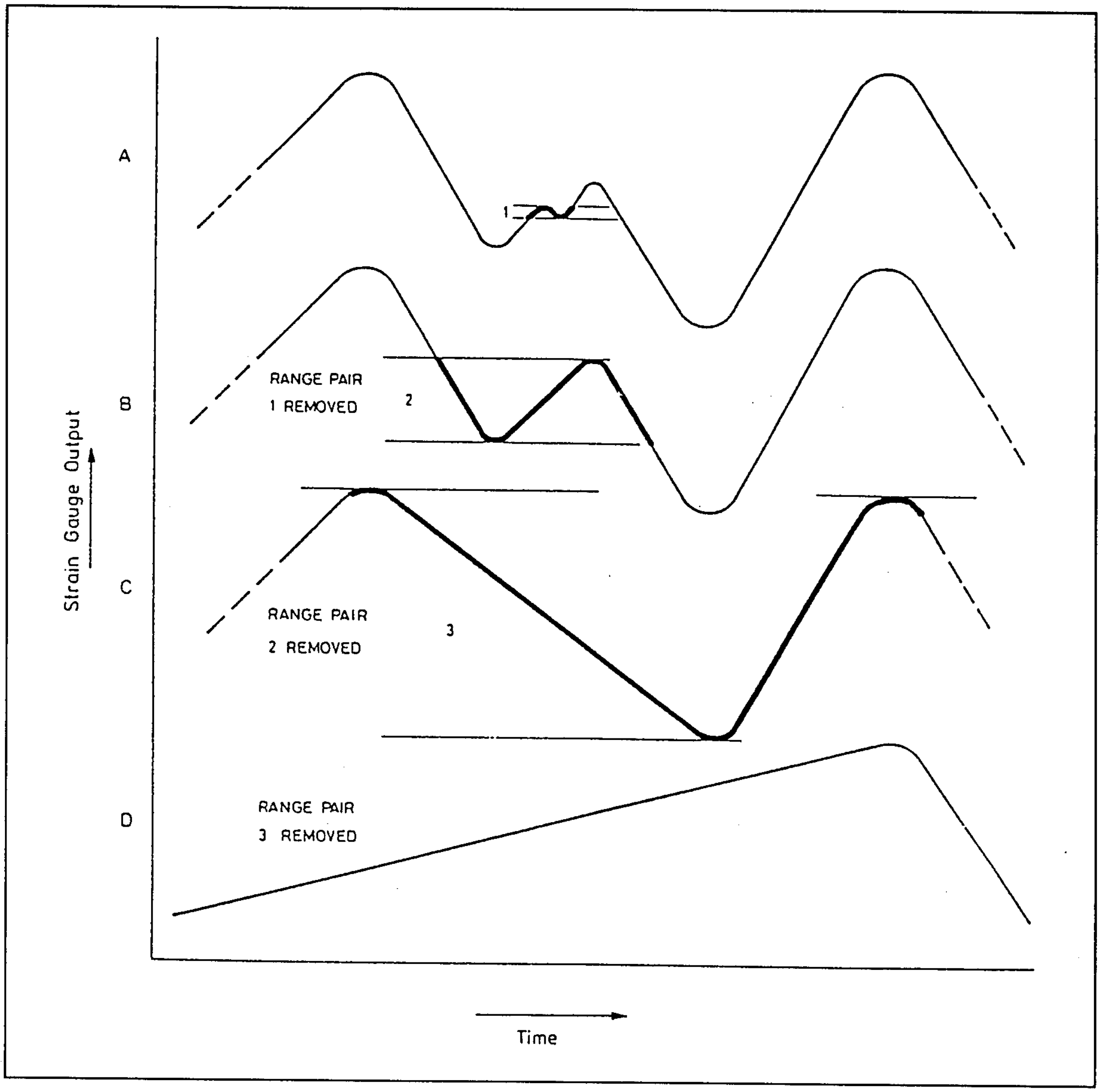
1. DADTA item locations 41b, 73 and 87a were not included in the RAAF F-111C DADTA.
2. There are a total of 8 equivalent DADTA Item locations and 14 nearby locations, giving a total of 22 locations, of which 19 were included in the RAAF F-111C DADTA.

2.1 Mature AFDAS Gauge and Equivalent DADTA Item Locations

A full DADTA study of the RAAF F-111 fleet is currently being performed by the manufacturer in the USA, Lockheed Aeronautical Systems Company (previously General Dynamics). The analysis is being performed for 71 parts/areas, using a spectrum which is representative of RAAF service. The spectrum was developed by processing the outputs from a parametric based flight data recording system known as the Multi Channel Recorder (MCR).

The MCR system was fitted to four RAAF F-111s. It was a more sophisticated fatigue load monitoring system than the counting accelerometer type "fatigue meters" fitted to all F-111 aircraft. The same system was fitted to a sample of the USAF F-111 fleet to obtain the spectra used in the USAF SLMP and DADTA analyses. The MCR system is now obsolete in both the USAF and the RAAF. The MCR operated by recording 24 parameters (including accelerations, configuration data and flight parameters such as altitude and airspeed) against a time base. MCR is a magnetic tape based analogue recording system. The parametric data was processed firstly by applying regression equations to obtain loads such as bending moments and shears, and secondly by processing into specific control point stress histories.

The AFDAS system monitors strain directly and processes the strain signal according to a range-mean-pair counting algorithm. This procedure is shown in the diagram below and is described in more detail in Reference 1. The strain signal can be converted to a stress, thus giving an equivalent input to a fatigue analysis as the MCR generated stress history.



Range-mean-pair Representation of Strain History (Reproduced from Reference 12)

The AFDAS system has the potential to monitor eight of the DADTA items directly, and a further nine may be feasible with a simple "scaling factor" applied to the data. Monitoring of other locations may also be possible with more complex transfer functions. Monitoring in terms of loads such as Wing Pivot Bending Moment (WPBM) also appears feasible to some extent. This is possible because the load to stress equation as given in Reference 12 for DADTA item 86 (for example) is a function of WPBM only.

Even those AFDAS gauge locations identified as nominally equivalent to DADTA item locations require a scaling factor, albeit relatively simple, to convert the AFDAS gauge output to a stress spectrum for the DADTA control point. This is because for practical installation reasons the exact location of the gauge may be several millimetres from where the DADTA stress spectrum is to be determined. Also, at the very least, a conversion from strain to stress is required.

The process of identifying these scaling factors and transfer functions will be assisted by locating strain gauges at appropriate locations on a full scale wing static load test being conducted at AMRL. The results from previous tests (References 7 and 8) will also be considered. The current round of testing will include various wing sweep angles. This will be possible due to modifications being performed on the AMRL test rig. The ability to test at various wing sweep angles and the fact that the outboard section of the Wing Carry Through Box (WCTB) will then undergo representative loading means that AFDAS gauge location C1, DADTA Item 136 (the WCTB lower lug) will be gauged and monitored.

The results of this review of AFDAS gauge locations have therefore identified the starting point for the transfer function and scaling factor development work. The results also provide valuable data for the strain range review because a significant activity in that task will be to relate the MCR derived stress spectrum for the DADTA Items to an anticipated spectrum at the AFDAS gauge locations.

3. Specified Test Wing Gauges

As discussed in the previous section, a full scale wing static load test is to be performed at AMRL. Strain gauges are to be located where possible at both the AFDAS gauge and DADTA Item locations.

The relevant locations have been identified and gauges specified by me. Gauges will be fitted and monitored at the following locations:

a. AFDAS gauge locations W1, W3, W5, W6 and C1.

b. DADTA item locations 73, 86, 87, 87a, 92a, 92b, 136, 159, and 159a.

4. Co-ordination of AFDAS Data Gathering

The procedures for gathering, analysing and storing operational AFDAS data are not adequately defined. Data is being collected from operational aircraft, but up until now the data has not been analysed or examined in any way. Indeed the procedures cannot be fully developed until the roles and uses of AFDAS are defined and understood, and the data is known to be reliable and useful. A task was therefore identified to co-ordinate the AFDAS data gathering and analysis process.

There are currently three AFDAS modified aircraft located at Number 6 Squadron, RAAF Base Amberley, which have been producing data. They are the only aircraft from which operational data has been extracted so far. Data extraction commenced in August 1993. An outline of the current procedure is as follows:

a. The remote "End of Flight" switch is activated at the end of each flight, thus causing the range-mean-pair tables to be stored in blocks of one flight.

b. Once a month, a "download" is performed and the data is transferred to disks.

c. One disk is produced for each aircraft and these are forwarded to ASI Section at HQLC. The Squadron has the capability to interrogate and screen the data for errors, but so far they have not exploited this capacity fully.

All disks produced so far have been forwarded to AMRL for analysis and investigation. The data has been examined and found to contain numerous errors indicating both hardware and set up faults. The Squadron has been alerted to these faults and given advice on the necessary corrective action.

The corrective actions were performed in May 1994 and the information from subsequent flights has now been examined. The status of those flights is that numerous errors still exist. Some of these errors are caused by inadequate strain range settings. The other errors are due to the way the processing software handles a particular characteristic of the hexadecimal data. The processing software is currently being modified by Hawker de Havilland Victoria Limited (HDHV), and the strain range settings will be reviewed during the next phase of AMRL support work. These actions are anticipated to result in good usable data being obtained.

5. Development of a Correlation Procedure

AFDAS processing software developed by Hawker de Havilland Victoria Limited (Reference 9) includes routines to screen the data for potential errors including the following:

a. Documentary data discrepancies including invalid tail number and dates/times.

b. Errors in the hardware including amplifier errors, low battery voltage and strain gauge errors.

c. Checking the range pair data outputs providing warnings if there are counts in the extreme windows, if there is an invalid range pair data structure (trough higher than a peak), or if the counts in any window exceed a certain predetermined value.

The data screening as described above is useful and necessary, but is very limited. The checks described in sub paragraph (c) above are defined based on expected theoretical outputs for a particular channel. For example, if the strain ranges have been properly set, counts would not be expected in the extreme windows. However, a method of checking the correlation of separate channels on the system both internally and against some expected value was identified as being required. A method which could be readily incorporated into a computer program would be the most practical solution.

Reference 3 details a method of correlating two channels from AFDAS when the data is presented in the form of two range pair tables. The idea is based on comparing the frequency distributions from two different sources to check for correlation. For example, one would expect to obtain good correlation between the vertical acceleration channel (Nz) and a strain channel which is primarily driven by Nz. In the Reference 3 report, data from the Mirage is used, and a comparison is made between the Nz channel and a strain gauge located on the wing main spar tension flange. Very good correlation results were obtained.

The Reference 3 correlations were performed by comparing four distributions obtained from the range-mean-pair tables; amplitudes, means, peaks and troughs. Summing the occurrences along the diagonals parallel to the leading diagonal produces the amplitude distribution, summing along the opposite diagonals produces the mean distribution, summing vertically produces the peak distribution and summing horizontally produces the trough distribution. The range-mean-pair tables for the Nz and strain data from Reference 3 and a demonstration of the summing procedure are shown in Figure 3. A check of the Nz range-mean-pair table against the fatigue meter data is also possible by running the range-mean-pair data through a fatigue meter logic algorithm.

Nz RANGE MEAN PAIR TABLE

summing lead diagonals produces occurrences of equal amplitude
(example shown has 39 occurrences with an amplitude of 2 levels)

Min Nz = -3.2g
Max Nz = +9.3g

summing opposite diagonals produces occurences of equal mean
(example shown has 23 occurences with a mean of level 6)

PEAKS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1															
2															
3															
4															
5															
6					15										
7		2	3		11	14									
8			1	1	5	10	8								
9				1	7	12		1							
10			1	1	3	5	2		1						
11		2	1		5	1									
12		2			2				1						
13															
14															
15															

T R O U G H S

STRAIN RANGE MEAN PAIR TABLE

summing verticals produces occurrences of equal troughs
(example shown has 7 occurrences at trough 6)

Min strain = -2300
Max strain = +2300

summing horizontals produces occurrences of equal peaks
(example shown has 33 occurrences at peak 12)

PEAKS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1															
2															
3															
4															
5															
6															
7															
8		1				1									
9															
10						1	1		11						
11							4		3	9					
12								2	8	19	4				
13							1		1	7	2				
14						1	1	1	6	5					
15															

T R O U G H S

Figure 3: Range Mean Pair Tables from Reference 3 Data

The Reference 3 correlation technique is based on the notion that even though a one-to-one relationship between the load (Nz) and strain ($\mu\varepsilon$) events cannot be extracted from the AFDAS strain range mean pair tables, the exceedence distributions of the two parameters should be similar. By comparing the two distributions, it is possible to determine if a linear relationship (as expected) exists between the two.

The Reference 3 procedures involve manual plotting and correlating to produce a final strain per g value. The same concepts have been used in a simplified procedure as described in the following section. This procedure was designed[1] to be automated so that it could be incorporated in a computer based screening system.

5.1 Simplified Correlation Procedure

Details of a simplified correlation procedure which has been developed are as follows:

a. Sum the lead diagonals, opposite diagonals, horizontals and verticals of the two range-mean-pair tables of interest, thus producing occurrence distributions based on amplitudes, means, peaks and troughs.

b. Express each occurrence as a percentage of the total.

c. Working in order of increasing load/strain, determine the mid-point of the current occurrence percentage at each load/strain level, cumulative with the previous occurrence percentages. For each load/strain level there is, therefore, one unique cumulative occurrence mid-point percentage.

d. Construct a table linking the cumulative mid-point percentages with the load/strain levels from the two range-mean-pair tables, performing linear interpolation as necessary to obtain one or other of the quantities.

e. Plot the load/strain values obtained from (d) against each other on a linear scale and fit a straight line to the result. The slope of this line is the quantity of interest, for example strain per g (same as strain per N_Z where N_Z is in units of 'g').

A complicating factor in the above procedure relates to the way the two channels to be correlated are expected to behave. Where they are expected to act in the same sense, that is an increase in one is expected to correlate with an increase in the other, the procedure is performed exactly as discussed. If the converse is true, then the range-mean-pair table must first be transposed before performing the comparison. The transposition effectively swaps the peaks and troughs. Where the channels operate in the same sense, a peak in one relates to a peak in the other, and a trough relates to a trough. Where the two channels operate in opposite senses, a peak in one relates to a trough on the other, so a transposition is required to one channel to allow a valid comparison to be performed.

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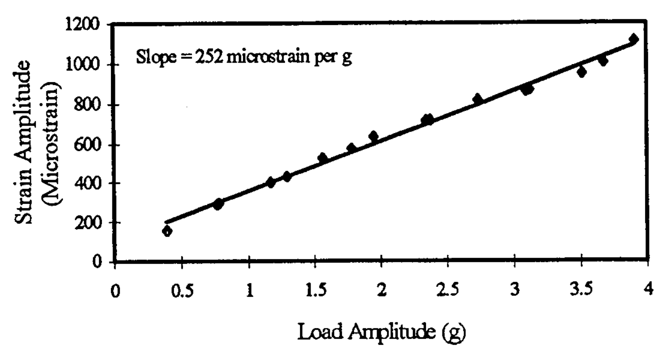
[1]This work was performed in conjunction with the AMRL F/A-18 Life Assessment Task.

This procedure has been applied to the Reference 3 data set. The results for the amplitude distribution are shown in the tables and figure below. A similar exercise was performed for the other three distributions and the results are shown at Annex B.

Strain versus Load Results Based on Amplitude Distributions from Reference 3 Data

Load Amplitude (g)	Occurrences	Cumulative Occurrences Mid-point Percentages	Strain Amplitude (με)	Occurrences	Cumulative Occurrences Mid-point Percentages
0.391	39	16.53	143.75	24	13.48
0.781	21	41.95	287.5	25	41.01
1.172	20	59.32	431.25	16	64.04
1.563	16	74.58	575	13	80.30
1.953	8	84.75	718.75	6	91.01
2.344	6	90.68	862.5	3	96.07
2.734	3	94.49	1006.25	1	98.31
3.125	1	96.19	1150	1	99.44
3.516	2	97.46			
3.906	2	99.15			

Cumulative Occurrences Mid-point Percentages	Load (g)	Strain (με)
16.53	0.391	159.7
41.01	0.767	287.5
41.95	0.781	293.4
59.32	1.172	401.8
64.04	1.293	431.25
80.30	1.782	575
74.58	1.563	524.4
84.75	1.953	634.7
90.68	2.344	714.3
91.01	2.378	718.75
94.49	2.734	817.6
96.07	3.097	862.5
96.19	3.125	870.2
97.46	3.516	951.7
98.31	3.672	1006.3
99.15	3.906	1113.1



The simplified procedure has been implemented on a PC based computer program. Features of the program include the following:

a. A parameter file is used to specify the strain/load ranges, expected correlation[2] values, channels for comparison and whether transposition of one channel is required. The file is customised as necessary to suit the particular aircraft type. The program is applicable to any AFDAS aircraft.

[2] Based on theory and/or separate testing and regression analysis.

b. The program computes the slope (strain versus g or strain versus strain) relating to the four distributions (amplitudes, means, peaks and troughs) and provides this slope, plus the average of the four, as the output. The results are compared to an expected range of correlation values (a user input).

The program has been tested against the Reference 3 data and the results are shown in the table below. This comparison shows that the program gives results identical with the manual process. The program was then checked against a series of F-111 flights as described in the next section.

Comparison of Strain per g Results

	Amplitudes	Means	Peaks	Troughs	Average
Reference 3 Results	347	346	359	381	358
Simplified Correlation Procedure (Manual)	252	350	314	313	307
Simplified Correlation Procedure (Computer Program)	252	350	314	313	307

Note: These figures were obtained by using the positive section only of the load/strain data.

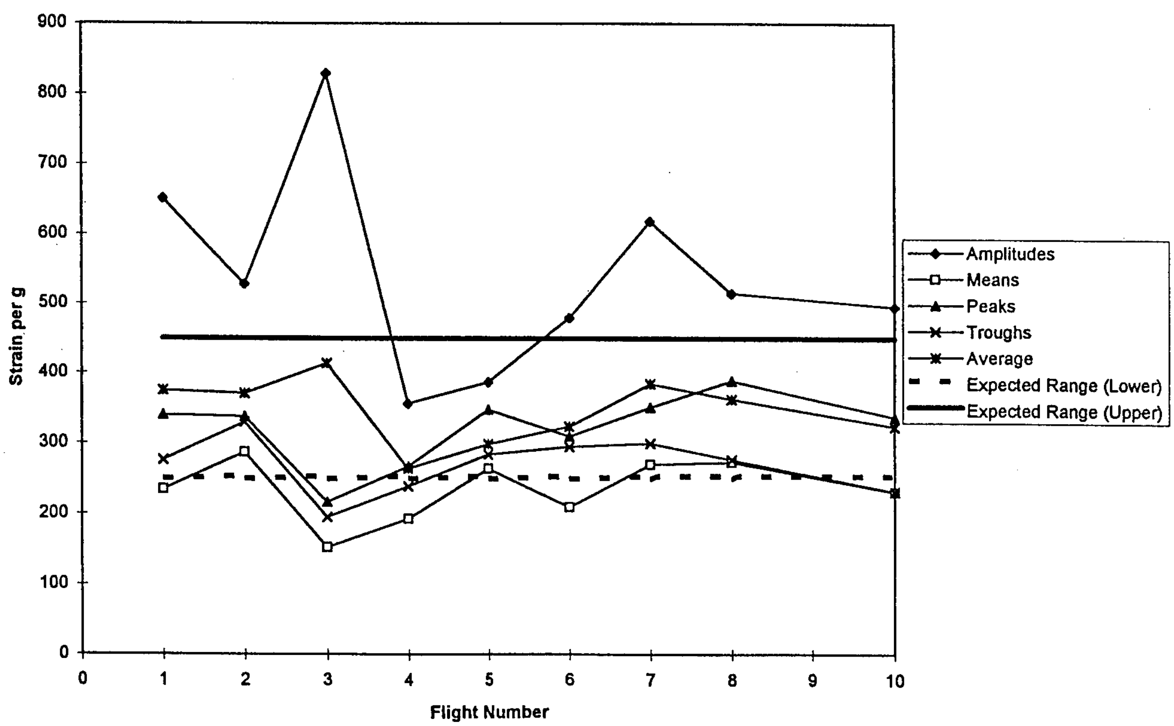
5.2 F-111 Test Data

Pending the availability of good quality operational data, a test was performed using F-111 AFDAS information from a series of flight trials performed in 1987. Nine flights of information were available from Reference 10. These flights were examined at the time and accepted as reliable and consistent.

For test purposes it was decided to run the program using the Nz channel and a strain channel expected to be highly Nz sensitive. Channel 0 relates to AFDAS gauge W1, which is located on the wing pivot fitting lower plate adjacent to fuel flow hole 58 in the centre web stiffener. This channel was compared with the C.G. acceleration (Nz, Channel 11). From static strain survey results, an expected strain per g value could be calculated. This varies with fuel burn, and for the F-111 on a typical mission a range of 400 to 600 microstrain per g was expected (a band of 200 microstrain that is per g). This is based on strain survey results (Reference 11).

The strain per g results for the 10 flights from Reference 10 are presented in the figure on page 15. A 200 microstrain per g band is plotted between 250 and 450 microstrain per g. The band was placed there to demonstrate that neglecting any offset error which may be present, the variation between flights in strain per g is generally less than the 200 microstrain per g band expected due to fuel burn. In

particular, the average of the strain per g calculated by the four different techniques is always within the 250 to 450 microstrain per g range. Flight three also stands out as being significantly different to the others, certainly in terms of the amplitude distribution, which may warrant further investigation to determine if there is anything unusual about that flight or if there is an error somewhere. These results indicate that it is feasible to set up an expected correlation range for particular channel comparisons and use this as a check on the quality and consistency of the data.



Strain per g for F111 Flight Trials

6. Discussion and Conclusions

The progress so far on the current AMRL F-111 AFDAS support activity has been summarised. The relationships between the current AFDAS locations to their SLMP location origins and the current DADTA Items have been defined. AFDAS data gathering activities have been reviewed and corrective actions initiated where necessary. An inter channel correlation procedure has been developed and demonstrated to be potentially effective as a data screening check.

All the activities to date have been focussed on increasing confidence in the F-111 AFDAS system by doing the following:

a. Establishing why the gauge locations were chosen and how they relate to other locations of importance for fatigue or structural life monitoring reasons.

b. Eliminating operational errors and difficulties which decrease the integrity of the data.

c. Developing new data screening procedures which check the data for inconsistencies and invalid results.

It had originally been planned to review the current strain range settings and develop transfer functions where required. These areas will be addressed as the task progresses into the next phase, that is identifying readily implemented uses of the AFDAS data.

The strain gauge location review work has revealed that many of the AFDAS locations have directly equivalent and/or nearby DADTA Item locations. The potential therefore exists to utilise AFDAS data to derive a stress spectrum for those locations. The nature of the loads to stress equations for some of these locations is such that it may be possible to also derive load spectra which could be compared to the current load spectra assumed for the DADTA. It therefore appears, that the AFDAS system will be able to provide useful information in terms of both loads monitoring and specific control point stress/strain monitoring.

7. Acknowledgments

The author wishes to acknowledge the assistance and support from Mr L. Molent of Airframes and Engines Division AMRL, in the development of the correlation procedure, and Ms A. Houston who developed the PC based software. Also to Messrs G. Swanton, B. Aktepe, R. Ogden, and K. Watters (F-111 Structural Integrity Task Manager) of Airframes and Engines Division AMRL, for their assistance and advice.

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6. General Dynamics report FZS-12-495, "DADTA: F-111A/E/D/F and FB-111A Final Analysis Details", Revision A, 29 May 1987

7. Anderson, I., Ferrarotto, P., Smith, D. "Strain Survey of an F-111C Wing Pivot Fitting", ARL Structures Technical Memorandum 523, Melbourne, January 1990.

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Annex A

Comparison of AFDAS Gauge Locations with Original SLMP Locations and DADTA Item Locations

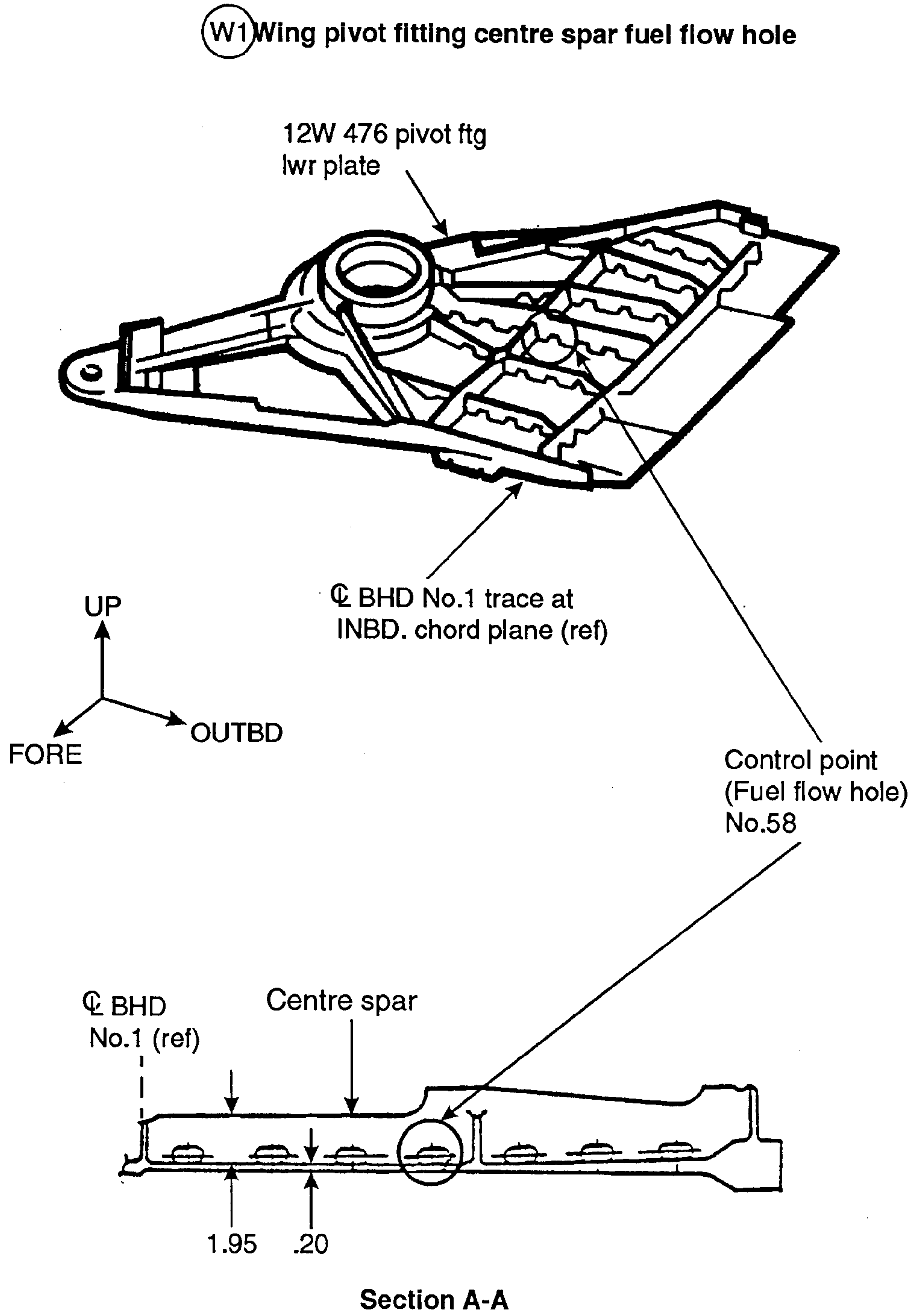
AFDAS Location:	W1
Channel:	0
SLMP Location:	W1
Equivalent DADTA Location:	86
Nearby DADTA Location	-

Figures:

A1: SLMP Location W1 (from reference 5)

A2: DADTA Item 86 (from reference 4)

A3: Location of AFDAS Gauge W1 (from reference 7)



Material: D6ac. H.T. 220-240 ksi-longitudinal grain direction
General dynamics control point:
(U.S.A.F. F111 SLM control point)

FIGURE A1. SLMP LOCATION W1 (FROM REFERENCE 5)

DADAT ITEM 86

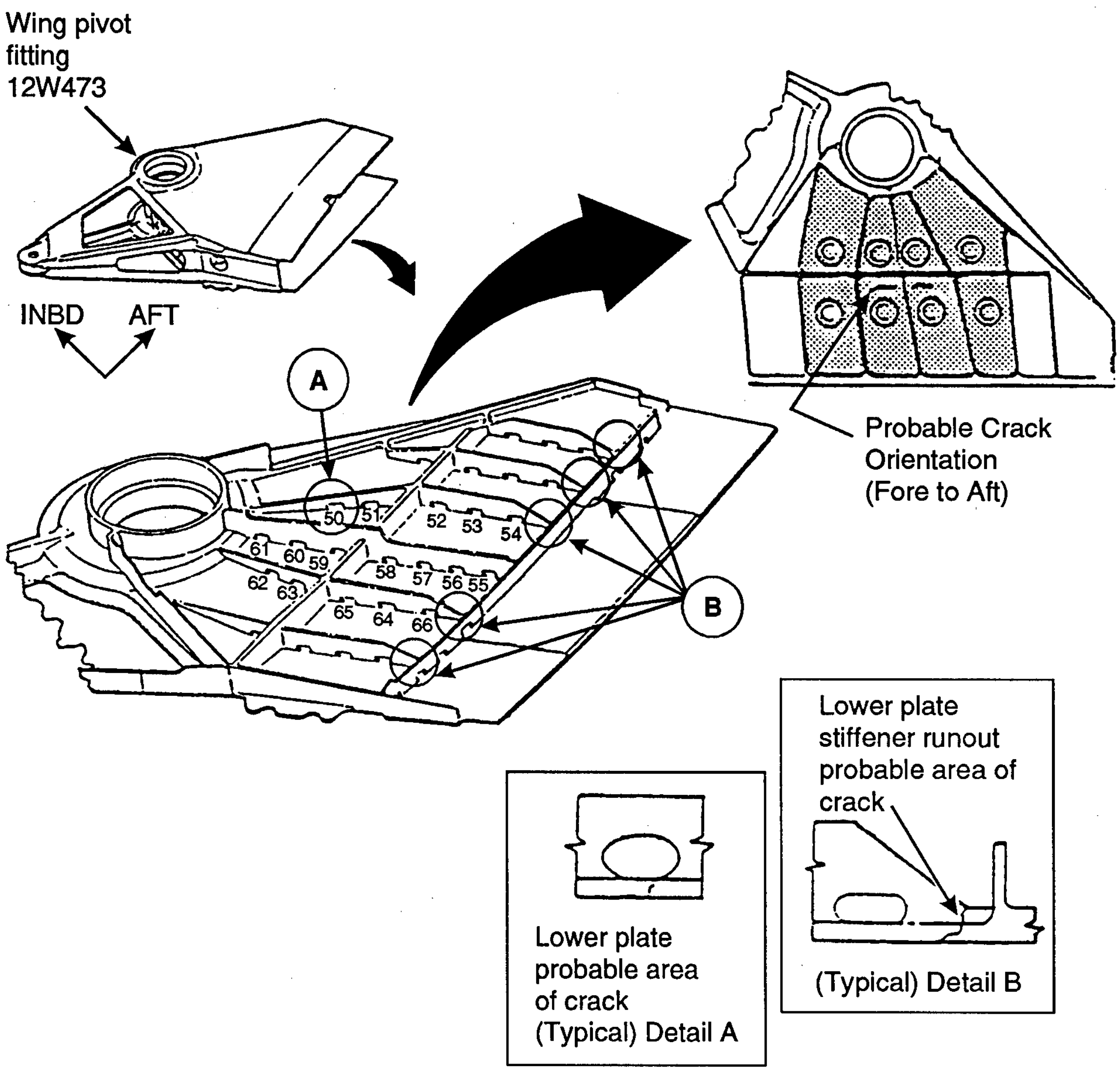


FIGURE A2. DADTA ITEM 86 (FROM REFERENCE 4)

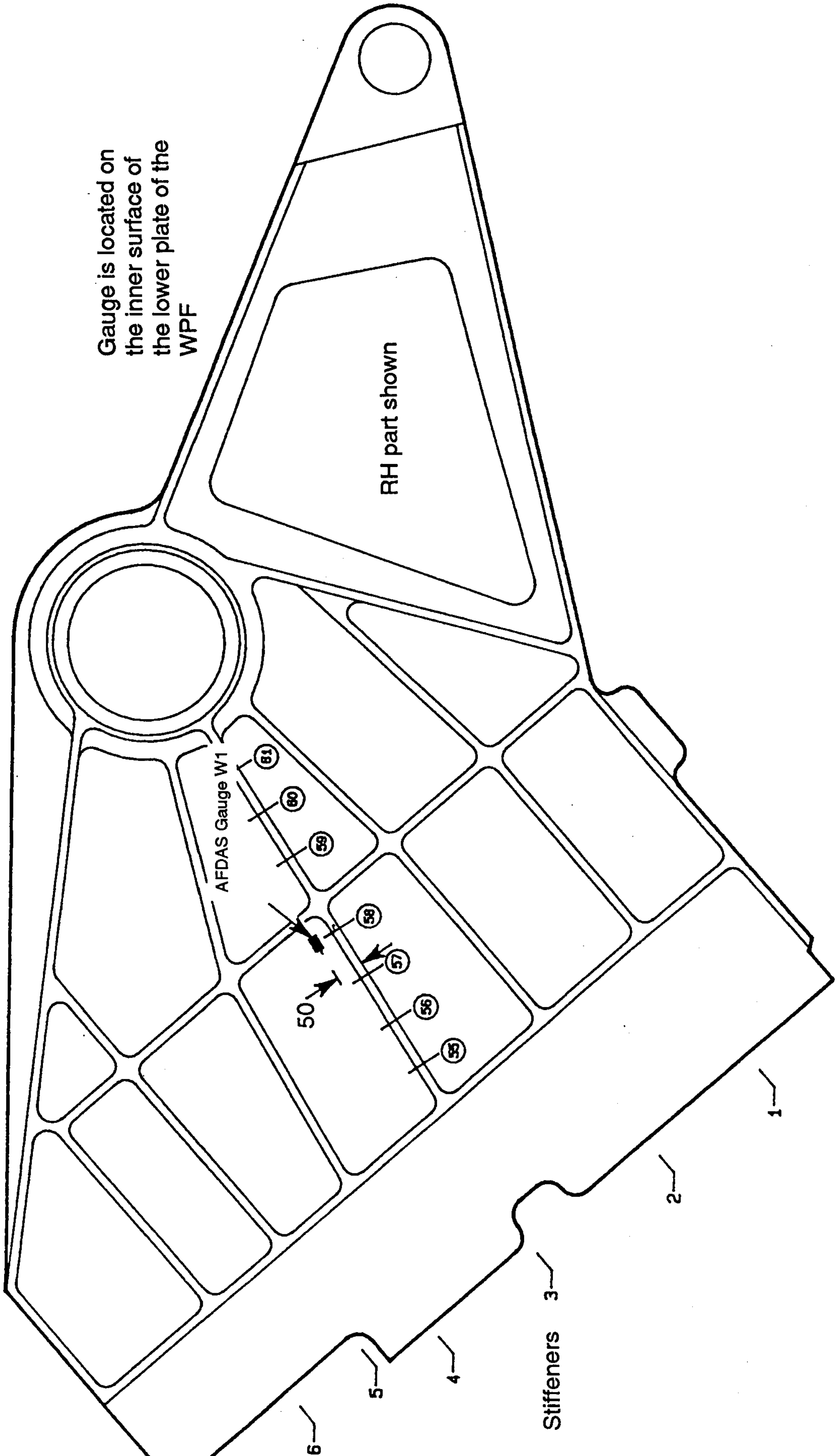


FIGURE A3. LOCATION OF AFDAS GAUGE W1 (FROM REFERENCE 7)

AFDAS Location:	W3
Channel:	1
SLMP Location:	W3
Equivalent DADTA Location:	-
Nearby DADTA Location	87,87a

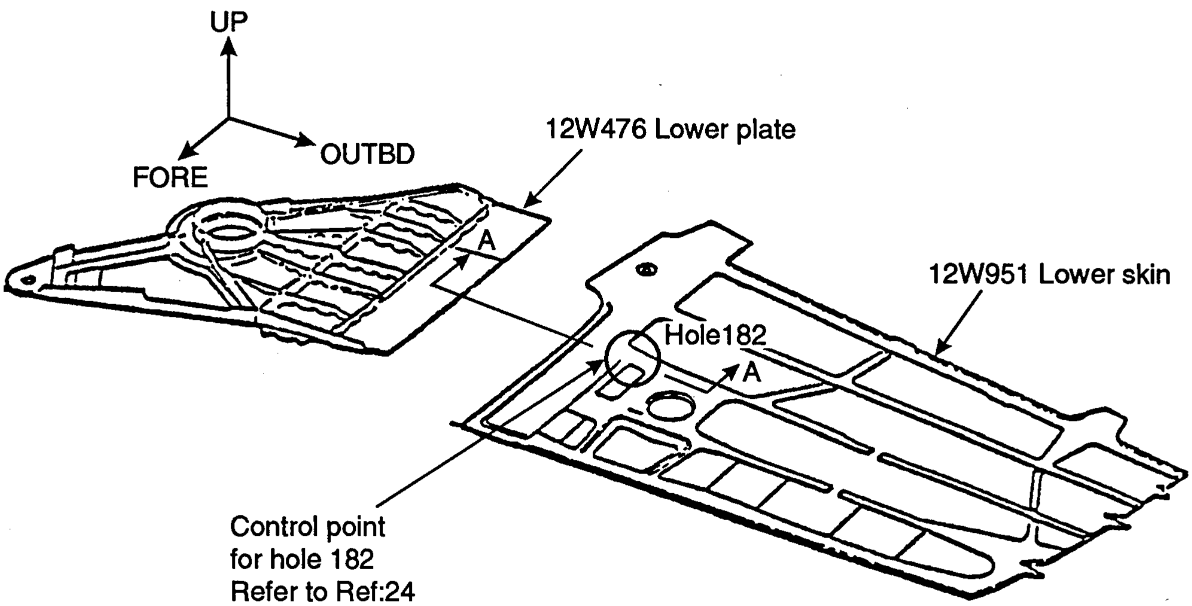
Figures:

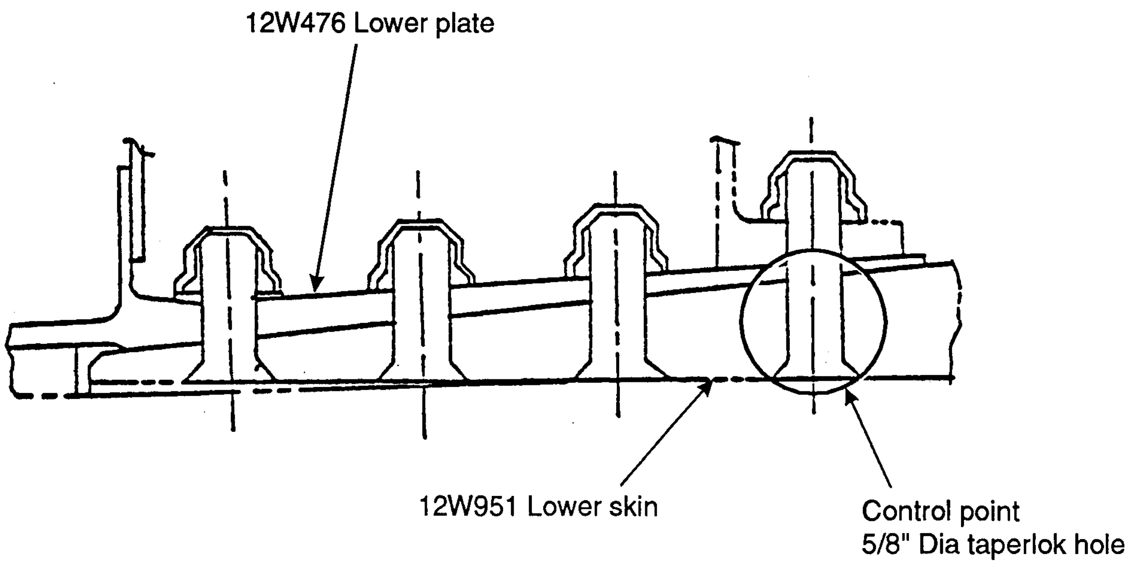
A4: SLMP Location W3(from reference 5)

A5: DADTA Item 87 (from reference 4)

A6: DADT Item 87a (from reference 6)

(W3) Wing lower skin-to-pivot fitting splice-aluminum



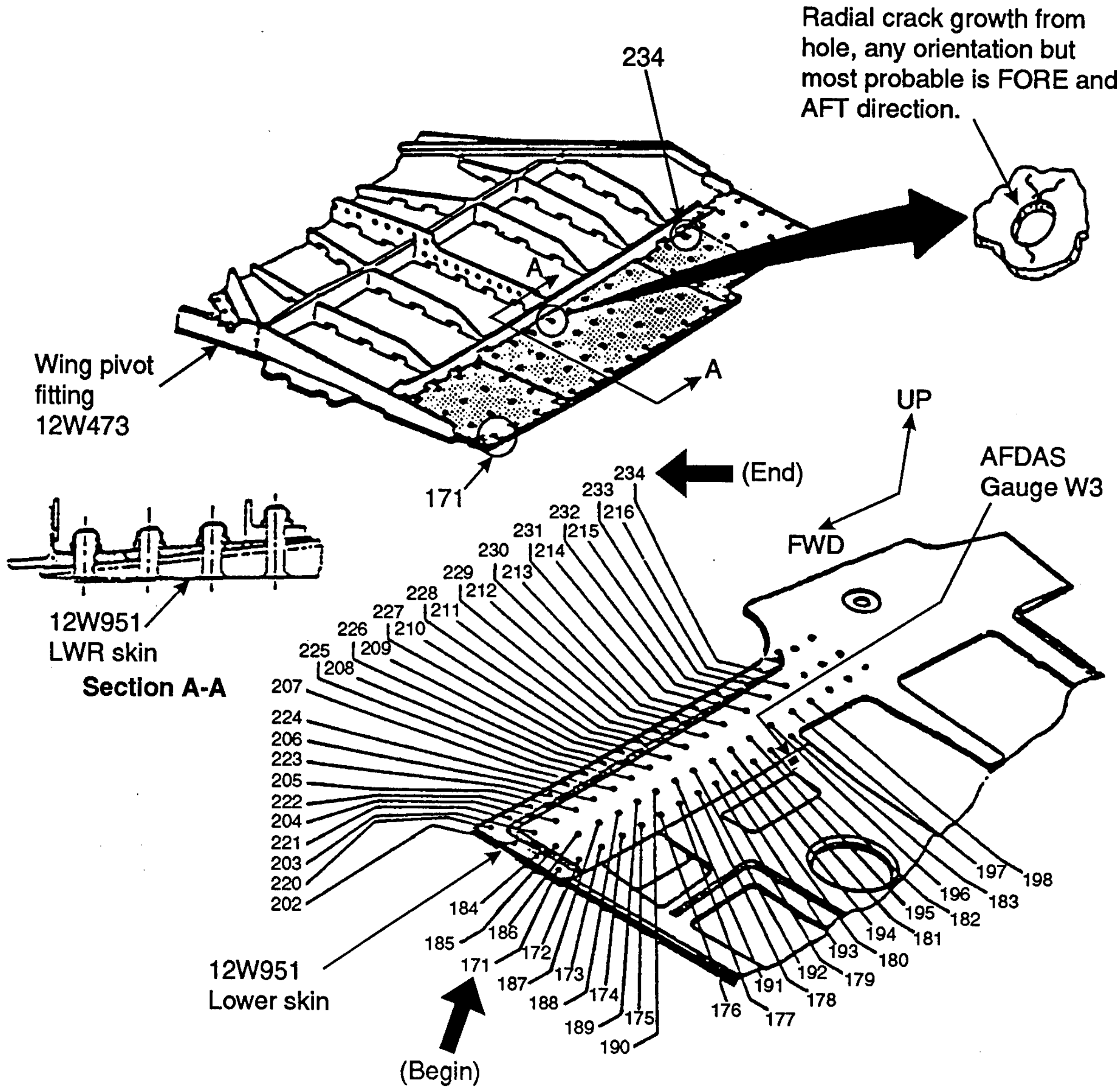


Section A-A showing splice

NOTE: AFDAS Gauge W3 is located on the inner surface of the wing lower skin (12W951) in line with and approximately four inches outboard of fastener hole#182.

FIGURE A4. SLMP LOCATION W3 (FROM REFERENCE 5)

DADTA ITEM 87



NOTE: AFDAS Gauge W3 is located on the inner surface of the wing lower skin (12W951) in line with and approximately four inches outboard of fastener hole#182.

FIGURE A5. DADTA ITEM 87 (FROM REFERENCE 4)

DADTA ITEM 87a

Wing pivot fitting lower plate
pivot fitting-to-lower wing skin splice
AFT spar area
12W476/ 12W504

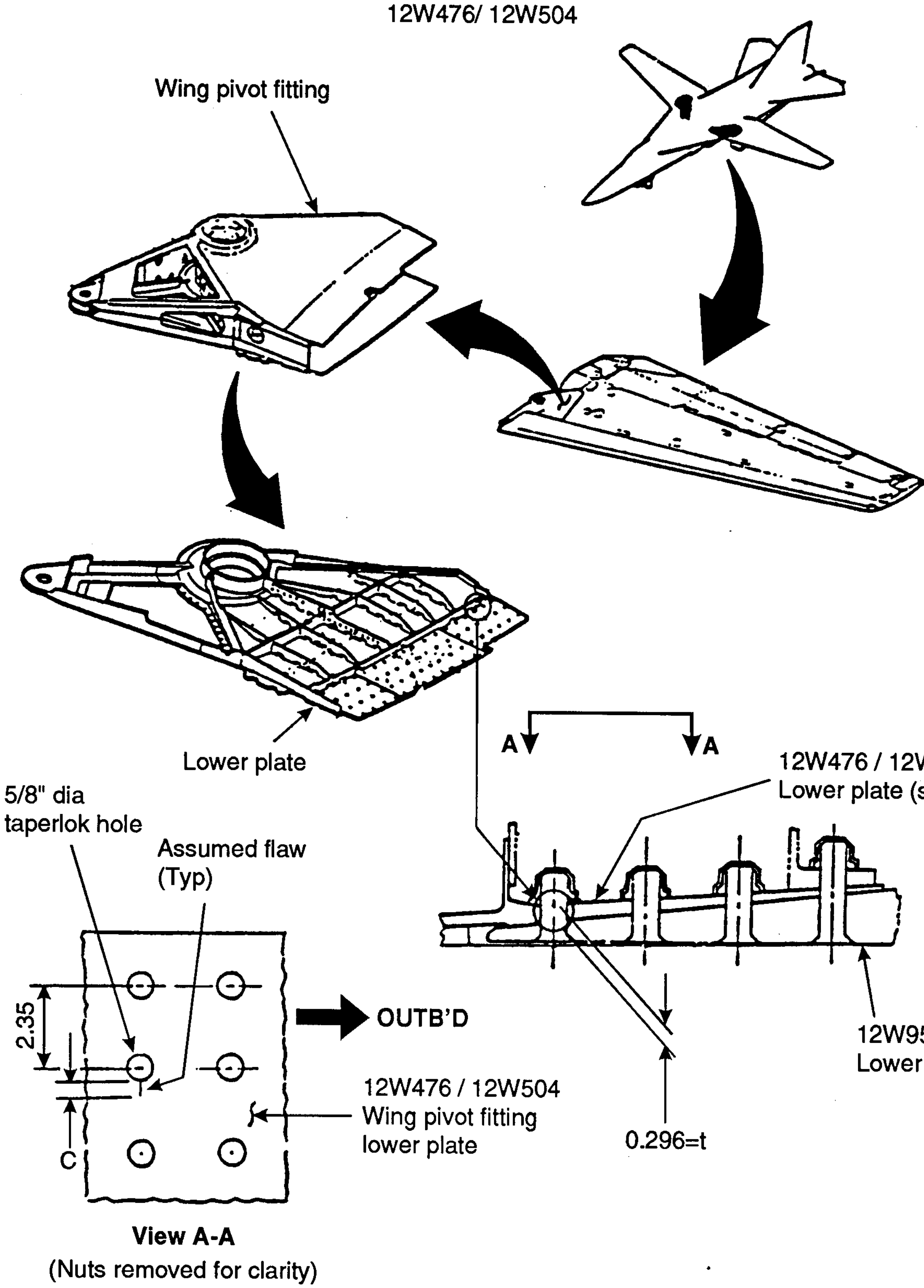


FIGURE A6. DADTA ITEM 87a (FROM REFERENCE 6)

AFDAS Location:	W5
Channel:	2
SLMP Location:	W5
Equivalent DADTA Location:	73
Nearby DADTA Location	-

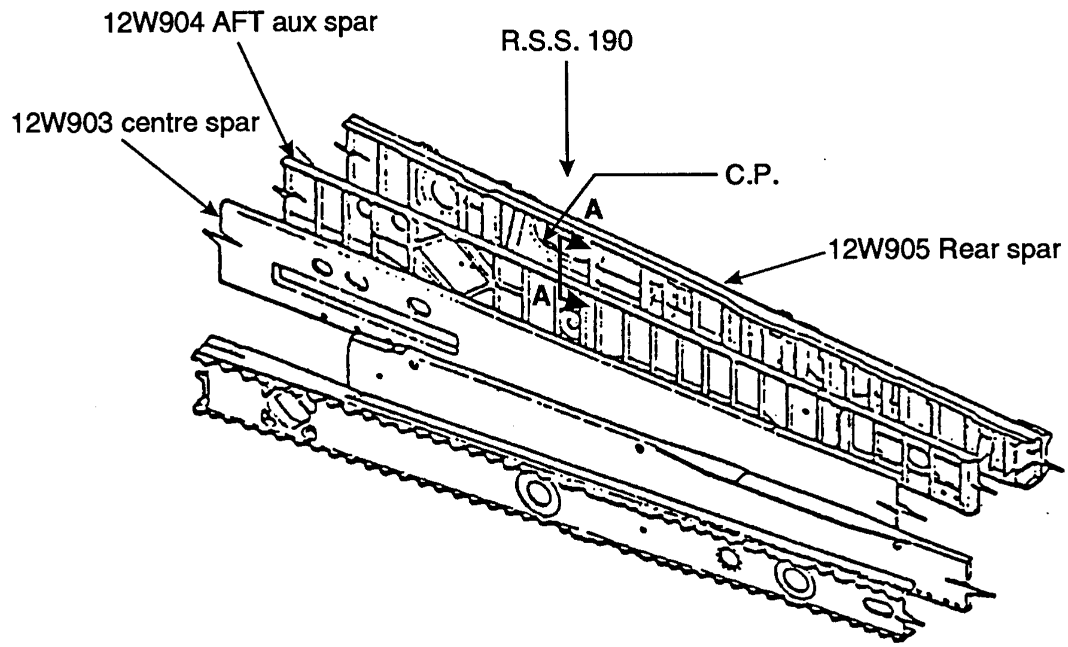
Figures:

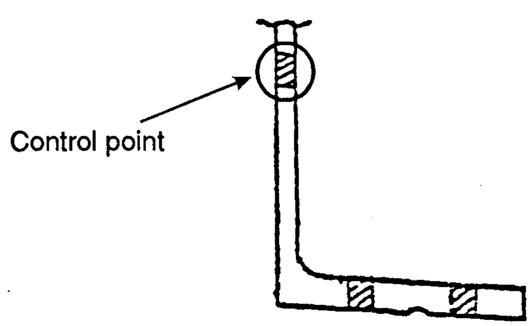
A7: SLMP Location W5(from reference 5)

A8: DADTA Item 73 (from reference 4)

A9: Location of AFDAS Gauge W5 (from reference 5)

(W5) **Wing rear spar in access hole at R.S.S.190**





Section A-A

FIGURE A7. SLMP LOCATION W5 (FROM REFERENCE 5)

DADTA ITEM 73

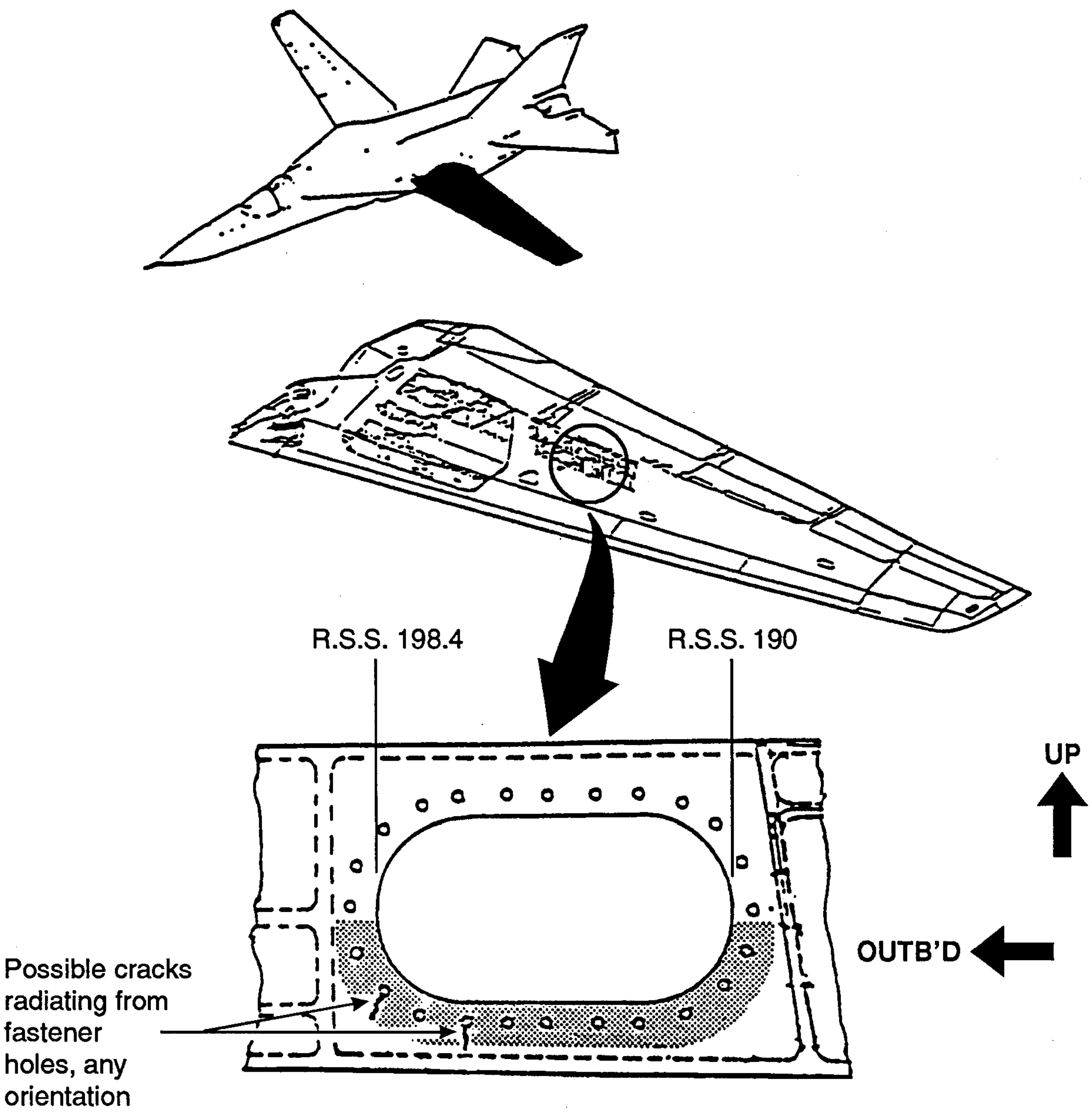
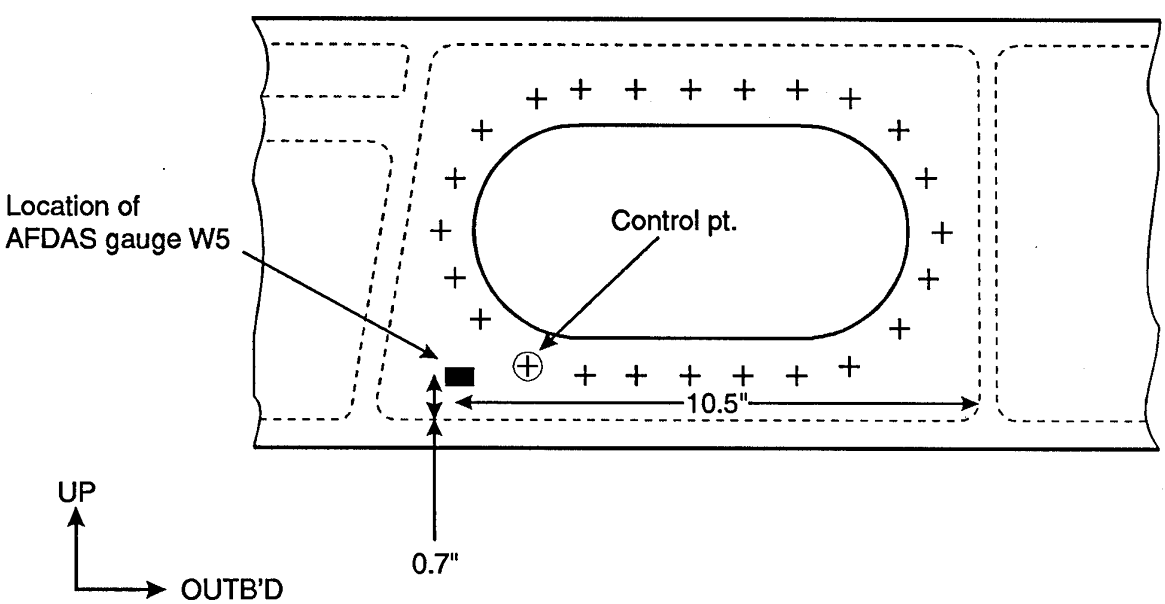


FIGURE A8. DADTA ITEM 73 (FROM REFERENCE 4)

Rear spar @ R.S.S. 190



View looking FWD at AFT face
RH wing shown

FIGURE A9. LOCATION OF AFDAS GAUGE W5 (FROM REFERENCE 5)

AFDAS Location:	C1
Channel:	3
SLMP Location:	C1
Equivalent DADTA Location:	136
Nearby DADTA Location	159,159a

Figures:

A10: SLMP Location C1(from reference 5)

A11: DADTA Item 136 (from reference 4)

A12: DADT Item 159 (from reference 6)

A13: DADTA Item 159a (from reference 6)

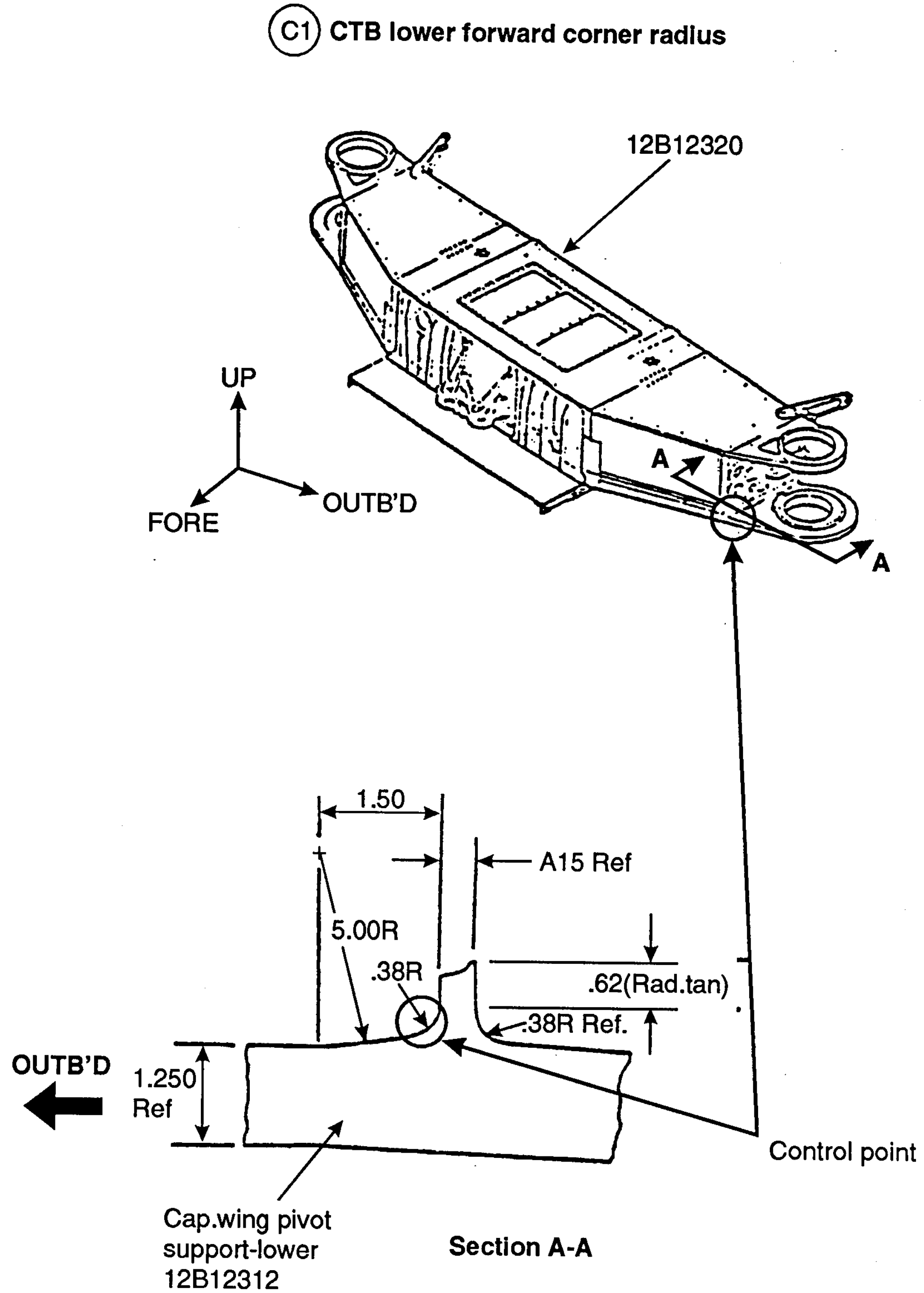
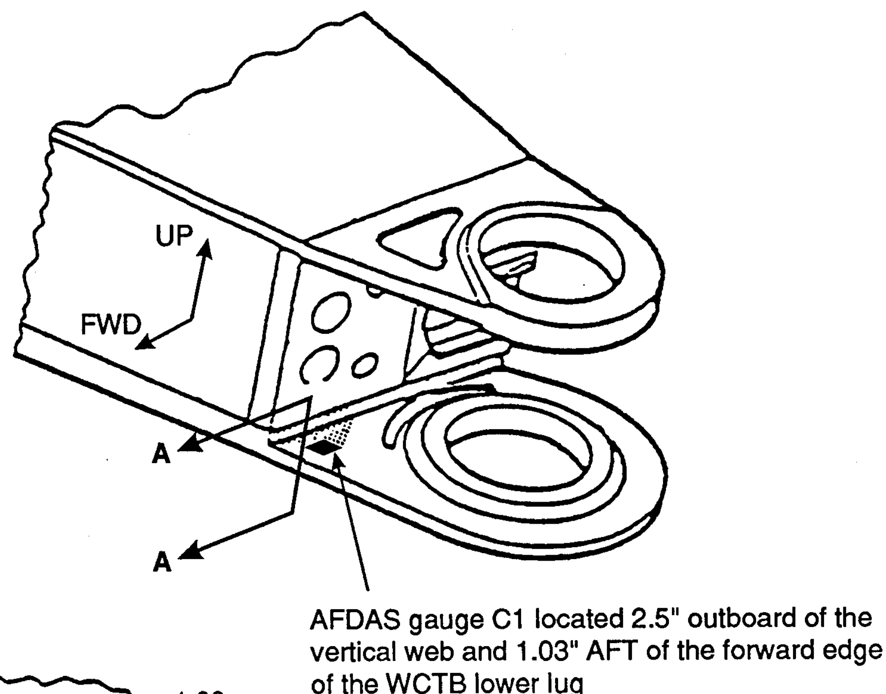
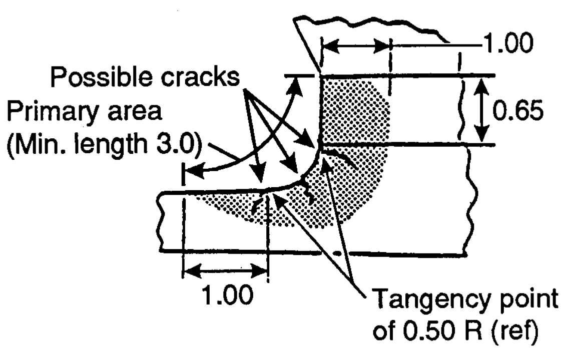


FIGURE A10. SLMP LOCATION C1 (FROM REFERENCE 5)

DADTA ITEM 136





Section A-A
Typical area (lower corners)

FIGURE A11. DADTA ITEM 136 (FROM REFERENCE 4)

DADTA ITEM 159
wing carry-thru box lower plate lug 12B7312

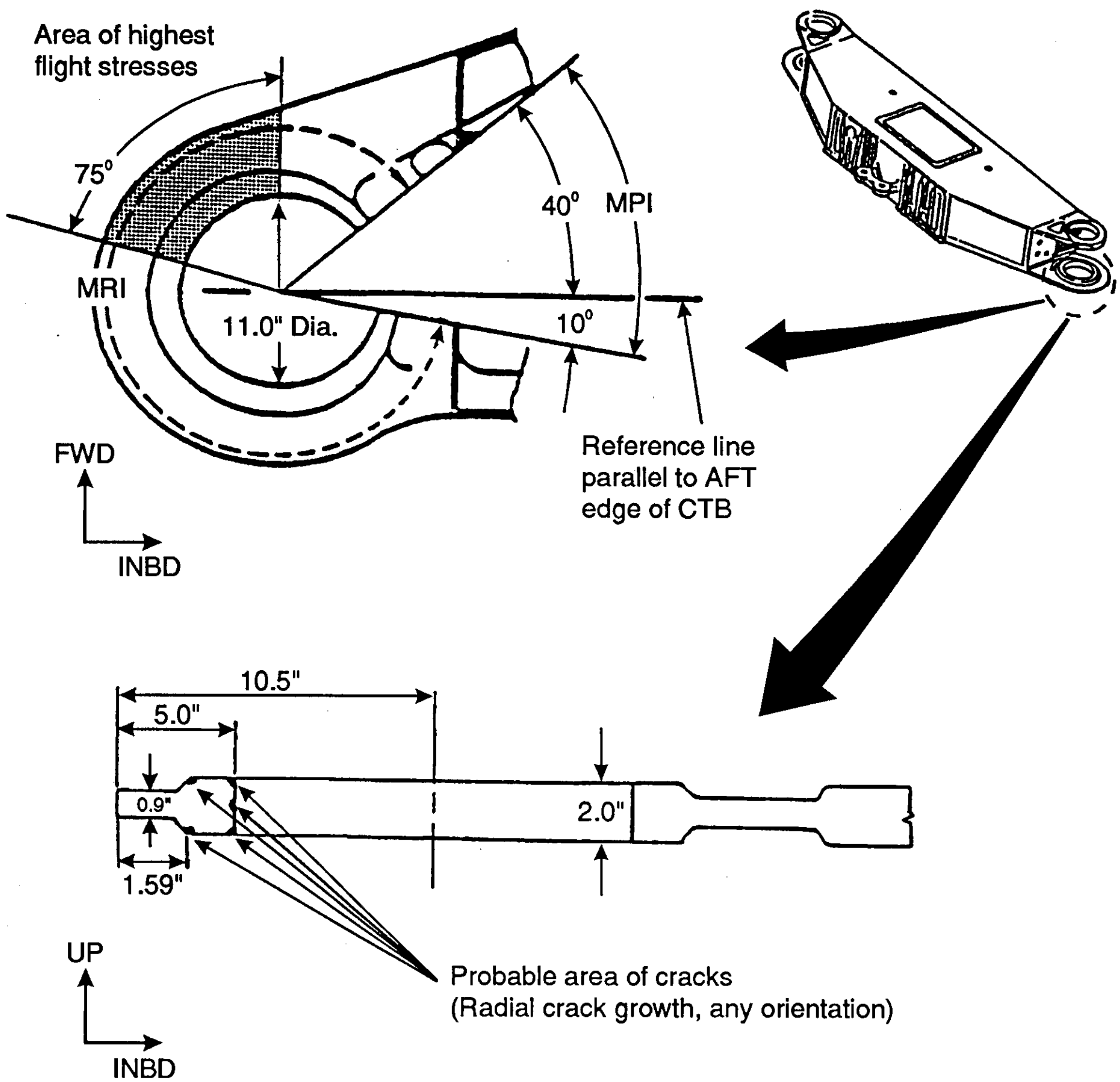


FIGURE A12. DADTA ITEM 159 (FROM REFERENCE 6)

DADTA ITEM 159a
wing carry-thru box lower plate lug 12B12312

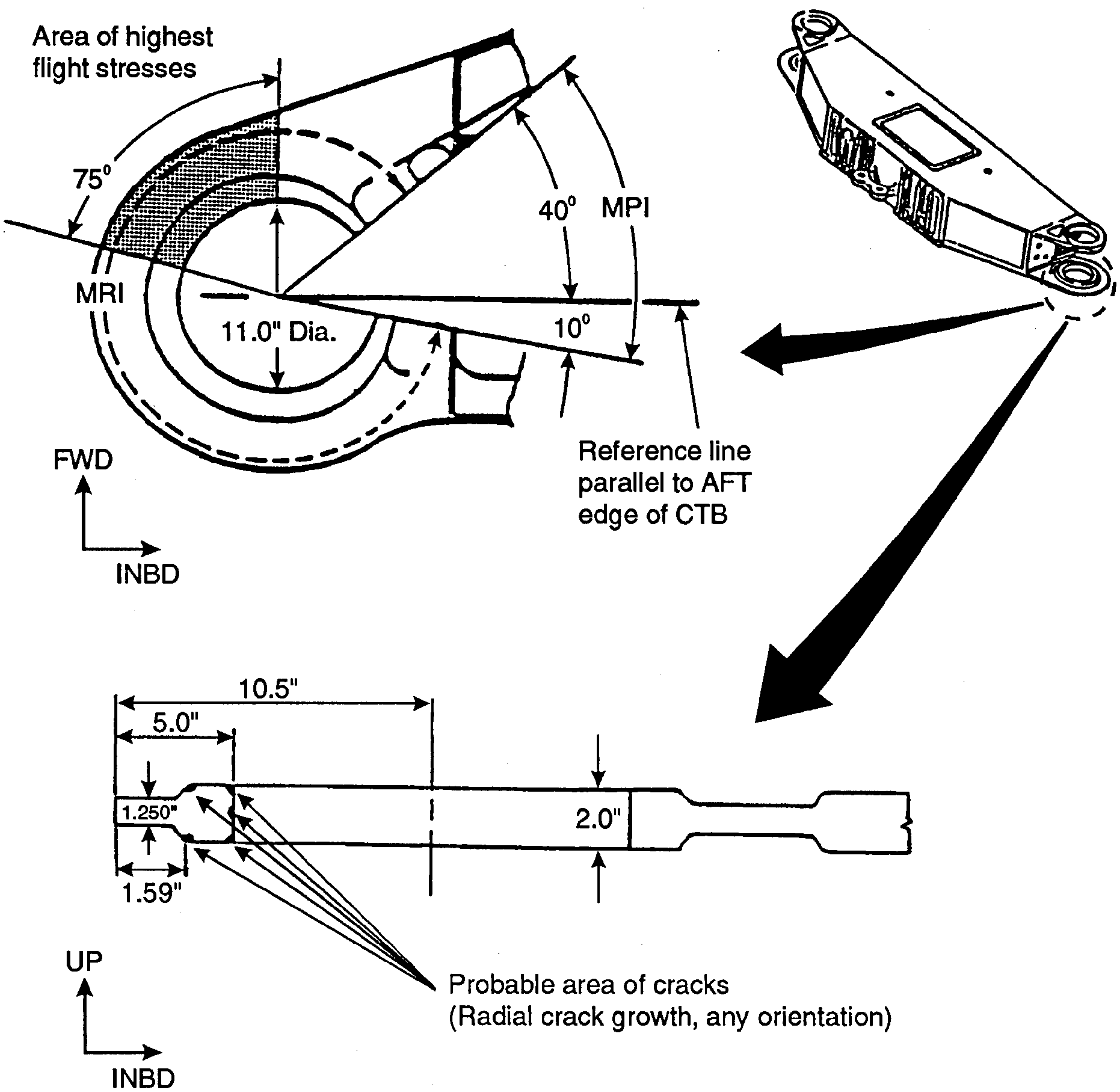


FIGURE A13. DADTA ITEM 159a (FROM REFERENCE 6)

AFDAS Location:	C2
Channel:	4
SLMP Location:	C2
Equivalent DADTA Location:	26, 26a
Nearby DADTA Location	27, 29

Figures:

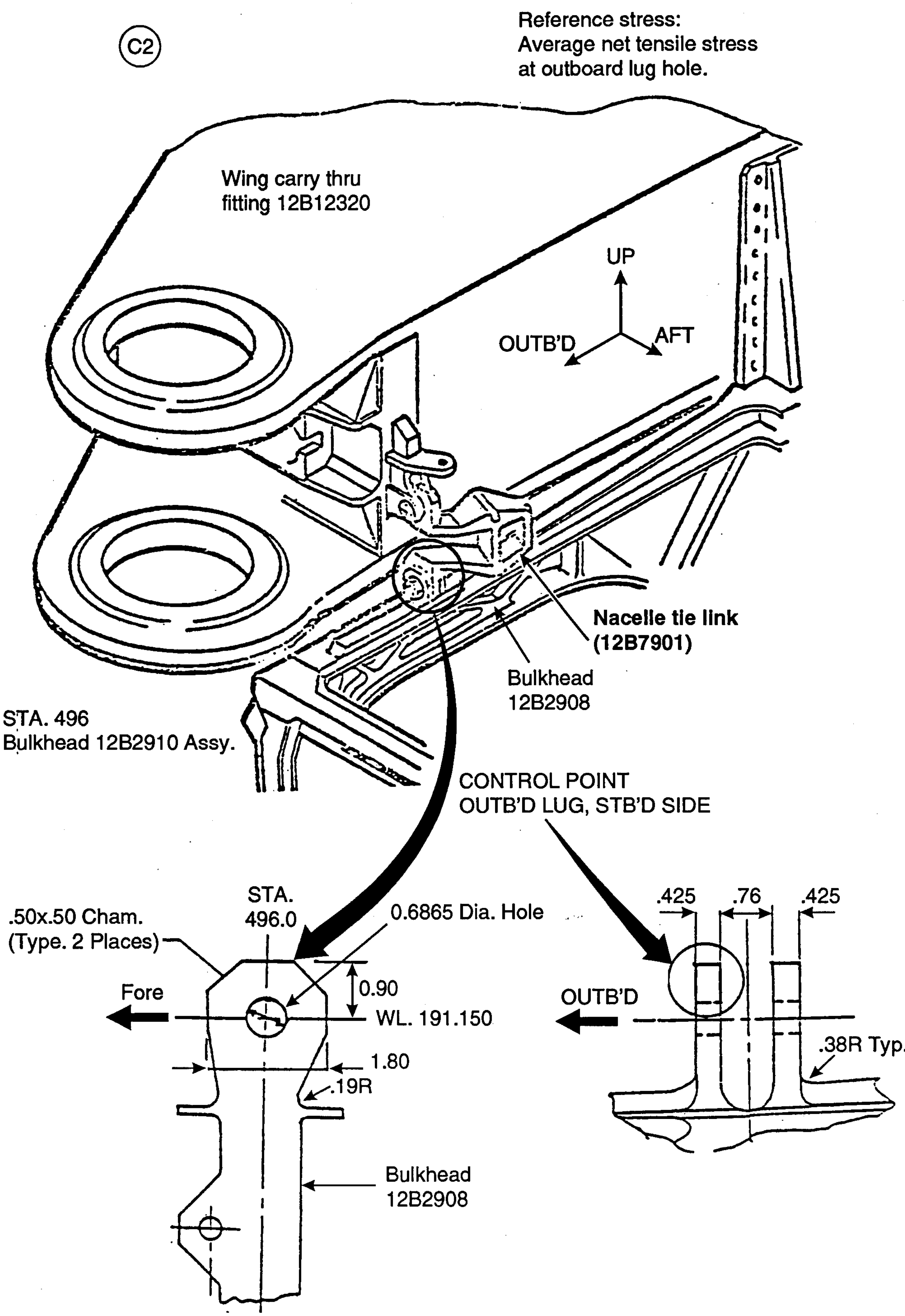
A14: SLMP Location C2(from reference 5)

A15: DADTA Item 26 (from reference 6)

A16: DADTA Item 26a (from reference 6)

A17: DADTA Item 27 (from reference 4)

A18: DATA Item 29 (from reference 6)



Material: D6ac. steel, 220-240 ksi. H.T.

FIGURE A14. SLMP LOCATION C2 (FROM REFERENCE 5)

Dadta item 26/26b
Nacelle fomer @ F.S. 496
Base of tie link lug (AFT, outside corner)
12B2910, 12B41210

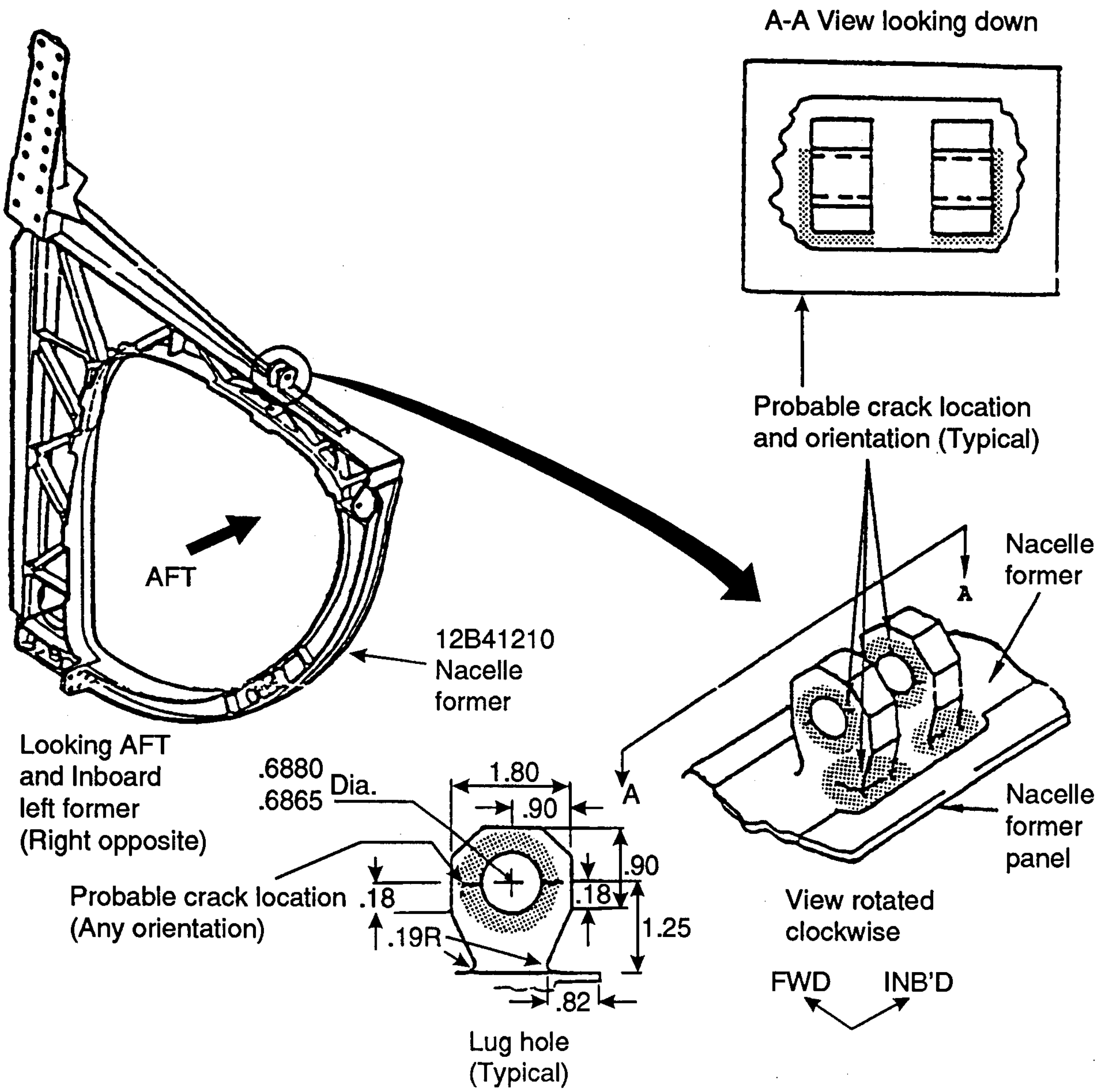
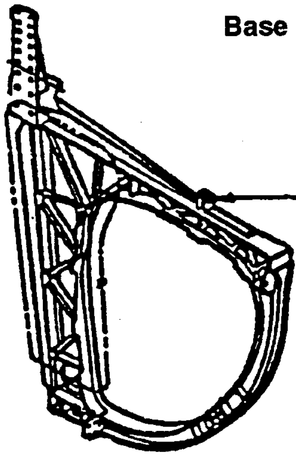
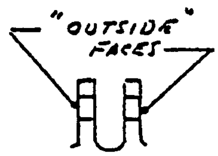
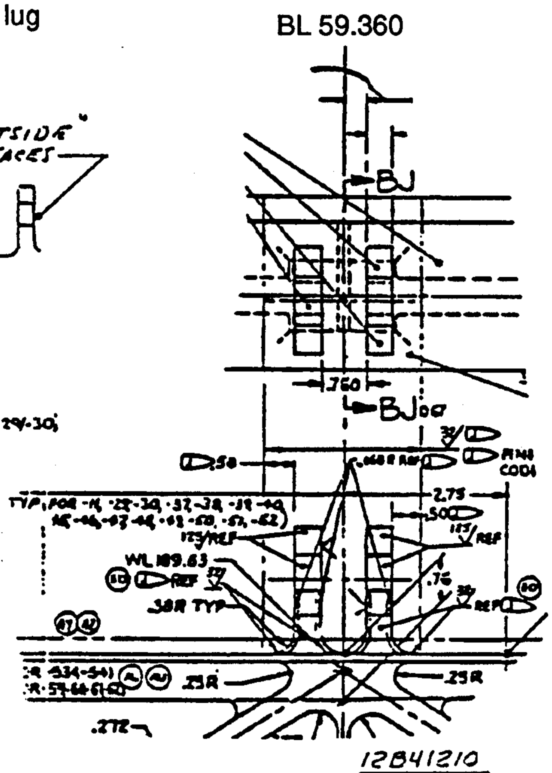


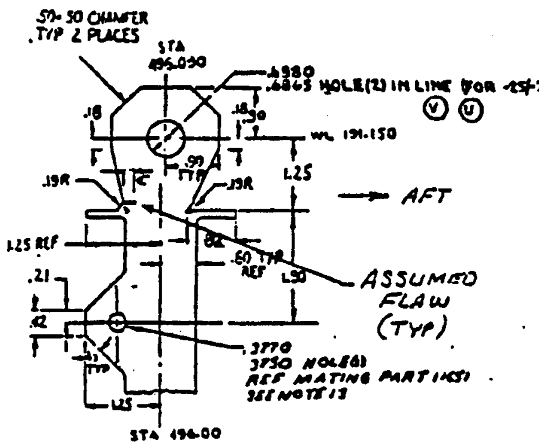
FIGURE A15. DADTA ITEM 26 (FROM REFERENCE 6)

DADTA Item 26@
Nacelle former @ F.S. 496
Base of link lug (FWD, outside corners)
12B2910, 12B41210

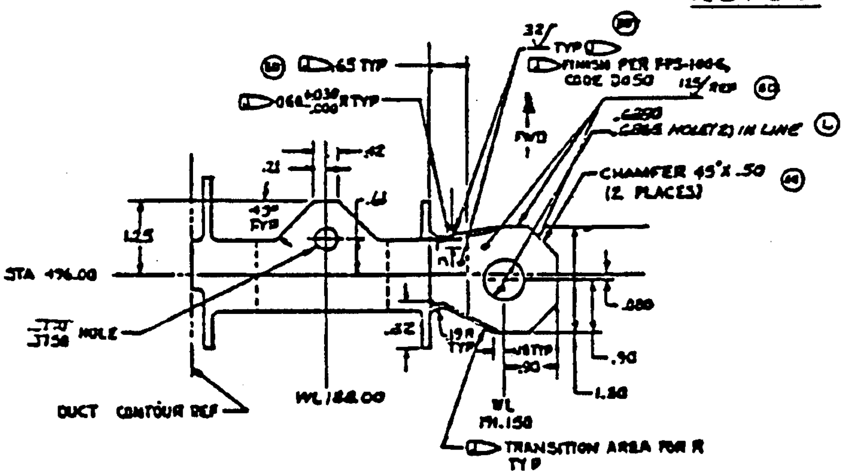








12B2908
(12B2910
NEXT ASSY)



12B41210

FIGURE A16. DADTA ITEM 26a (FROM REFERENCE 6)

Dadta item 27

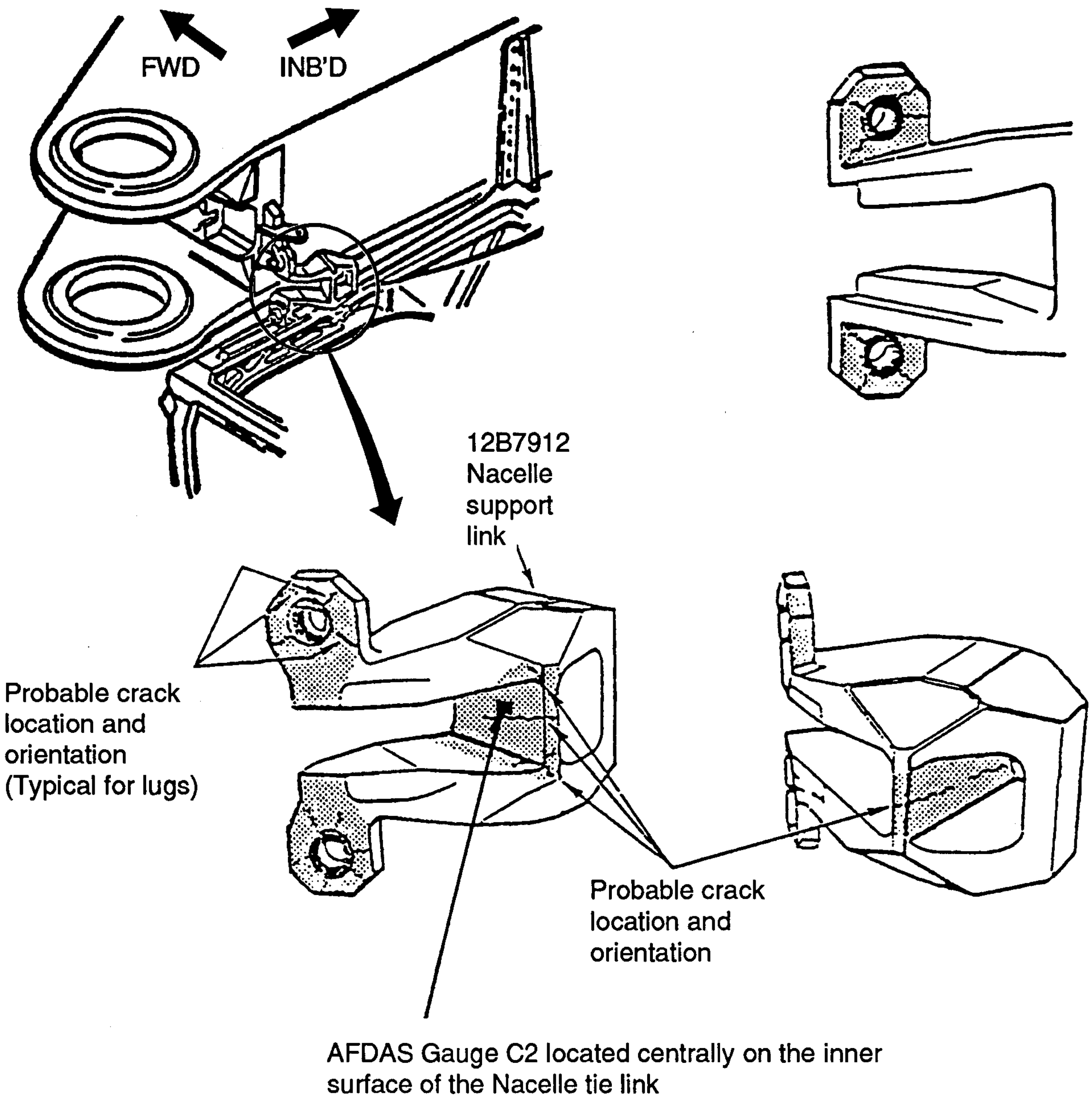


FIGURE A17. DADTA ITEM 27 (FROM REFERENCE 4)

Dadta item 29
Nacelle tie link support lug
12B7901

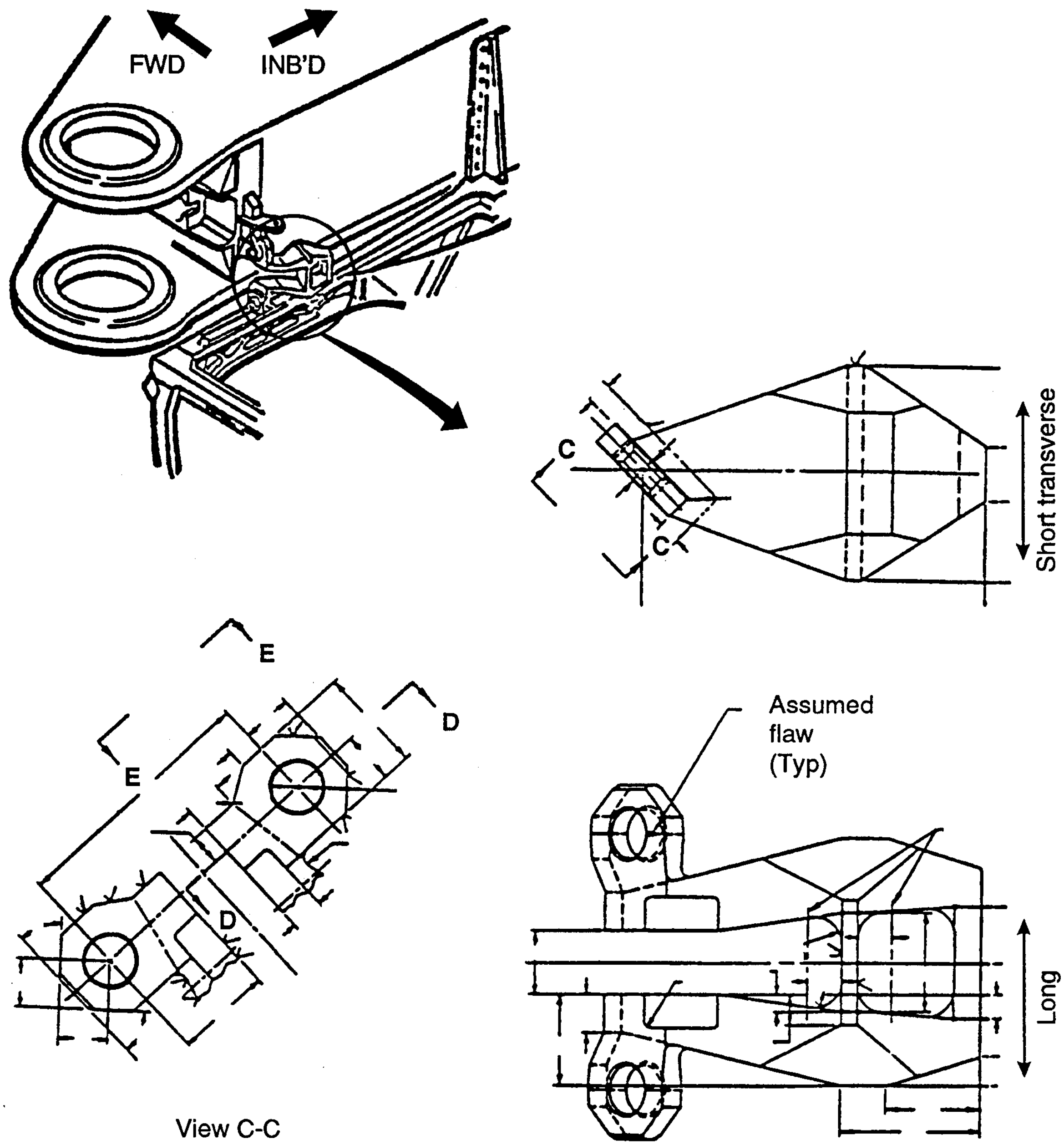


FIGURE A18. DADTA ITEM 29 (FROM REFERENCE 6)

AFDAS Location:	FF1
Channel:	5
SLMP Location:	FF1
Equivalent DADTA Location:	-
Nearby DADTA Location	-

Figures:

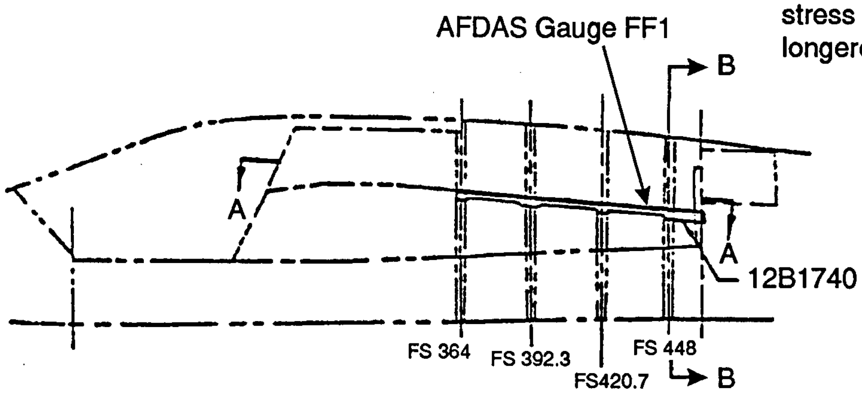
A19: SLMP Location FF1(from reference 5)

A20: Location of AFDAS Gauge FF1 (from reference 5)

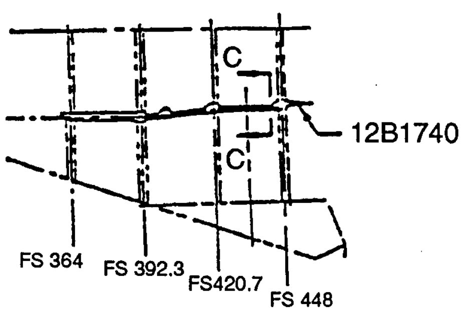
FF1 **Wing fuselage intersection longeron, F.S. 448**

Figure 3.9.0

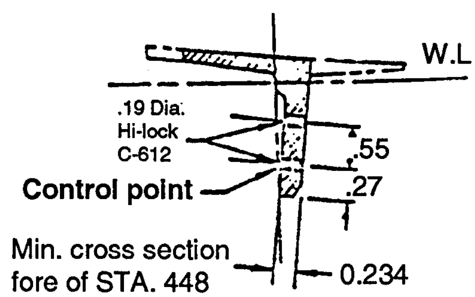
Reference stress
Average net tensile stress across longeron section.



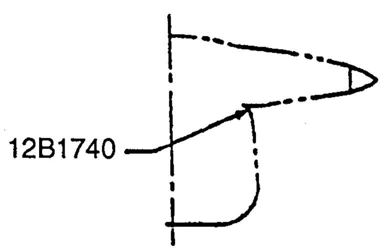
View looking INB'D



Section A-A



Section C-C
Rotated 90° CW



Section B-B

AFDAS Gauge FF1 is located on the 12B1740 longeron approximately four inches forward of F.S. 448

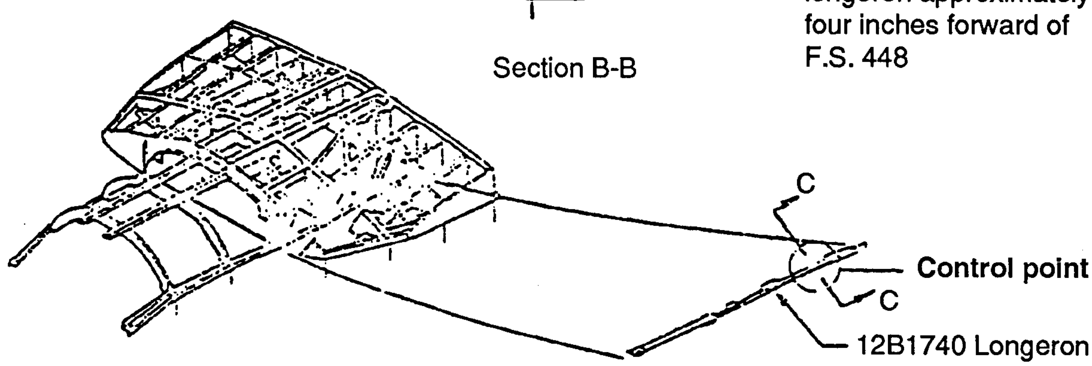


FIGURE A19. SLMP LOCATION FF1 (FROM REFERENCE 5)

Figure 3. 9. 1, Control point FF1

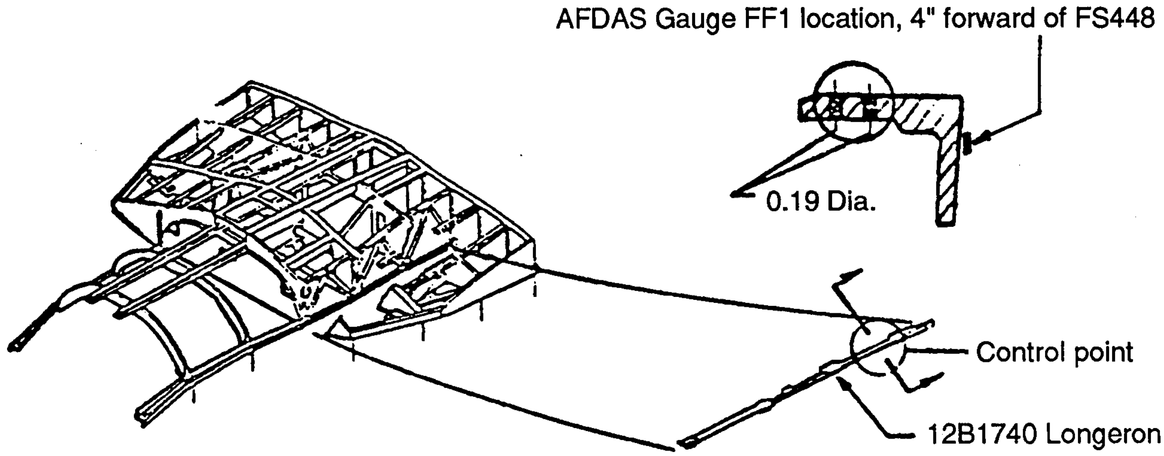


FIGURE A20. LOCATION OF AFDAS GAUGE FF1 (FROM REFERENCE 5)

AFDAS Location:	W6
Channel:	6
SLMP Location:	N/A
Equivalent DADTA Location:	92a, 92b
Nearby DADTA Location	-

Figures:

A21: Location of AFDAS Gauge W6 (from reference 4)

A22: DADTA Item 92a, 92b (from reference 6)

DADTA ITEM 92A

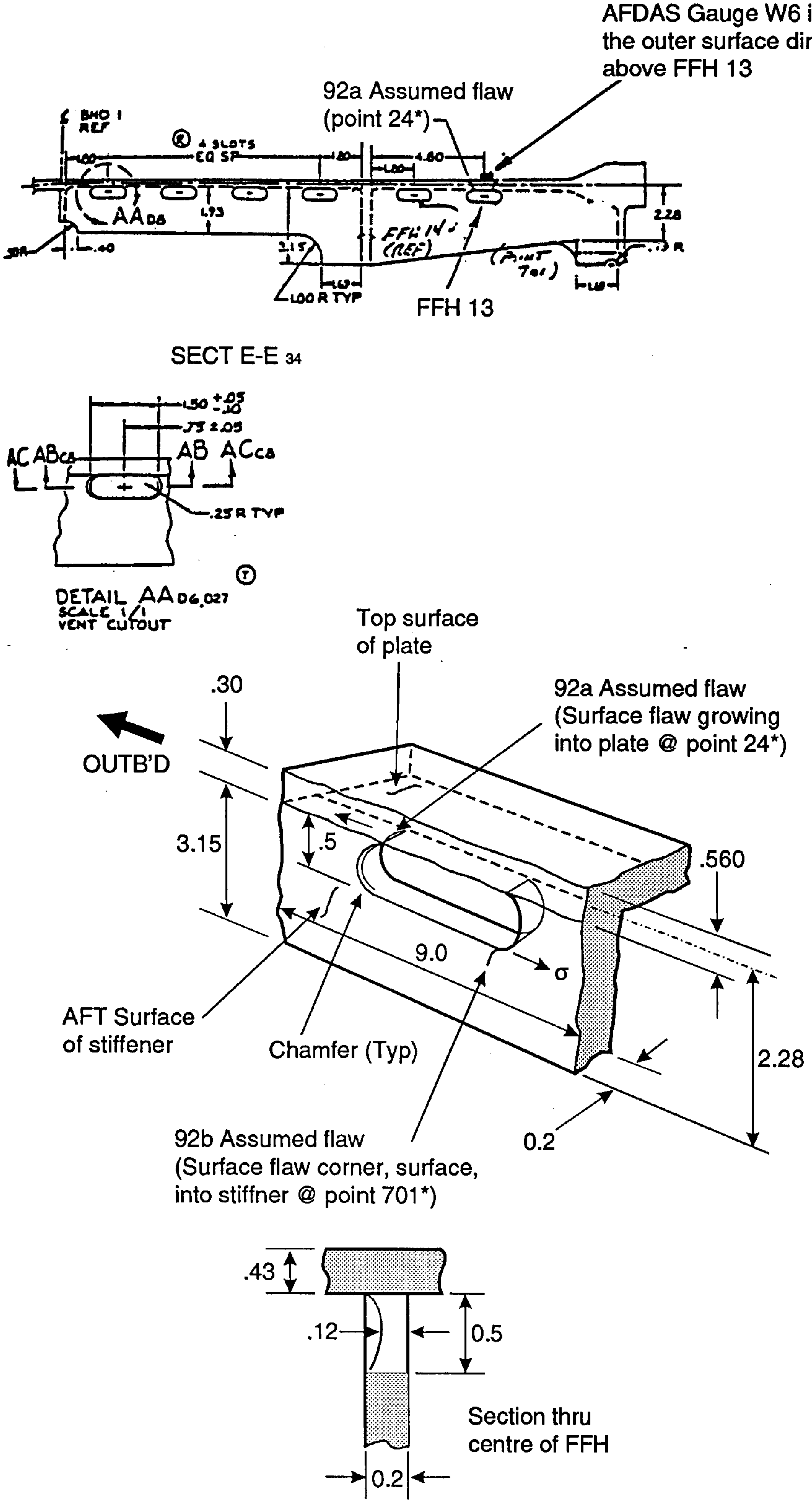
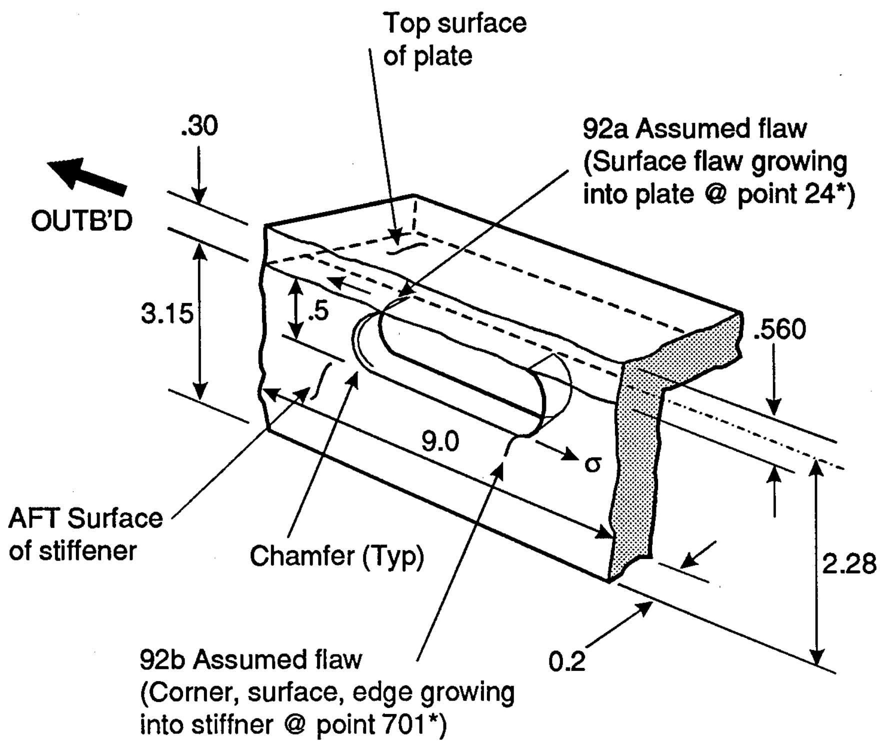


FIGURE A21. LOCATION OF AFDAS GAUGE W6 (FROM REFERENCE 4)

Figure A

DADTA ITEM 92a, 92b -Cont'd



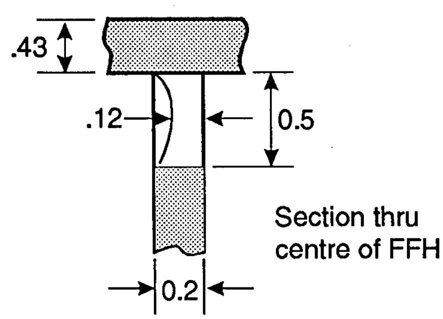


FIGURE A22. DADTA ITEM 92a, 92b (FROM REFERENCE 6)

AFDAS Location:	VT4
Channel:	7
SLMP Location:	VT4
Equivalent DADTA Location:	-
Nearby DADTA Location	41b

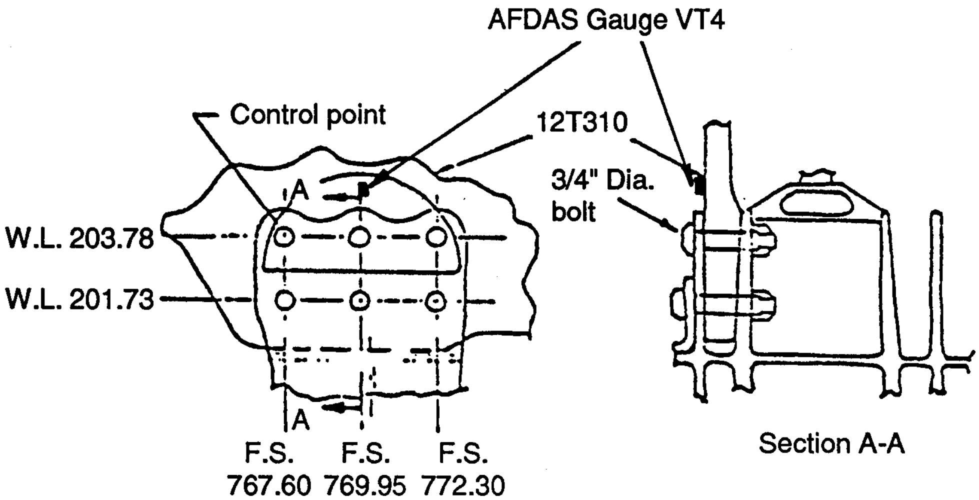
Figures:

A23: SLMP Location VT4 (from reference 5)

A24: DADTA Item 41b (from reference 6)

VT4

Upper bolt row in skin at the pedestal splice at F.S. 770.25



AFDAS Gauge VT4 is located approximately 2" above and in line with the centre and upper fastener at FS 769.95 and WL 203.78

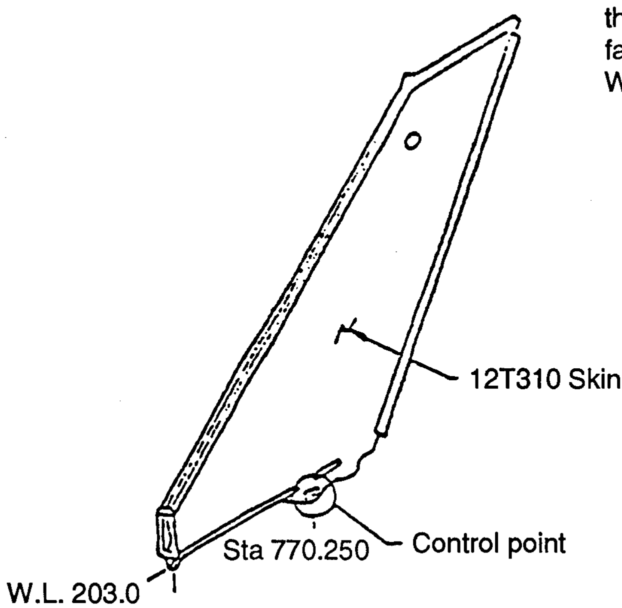


FIGURE A23. SLMP LOCATION VT4 (FROM REFERENCE 5)

DADTA ITEM 41b
Vertical stabilizer attach lugs @ 770.25
lower row of bolts holes
12B10520

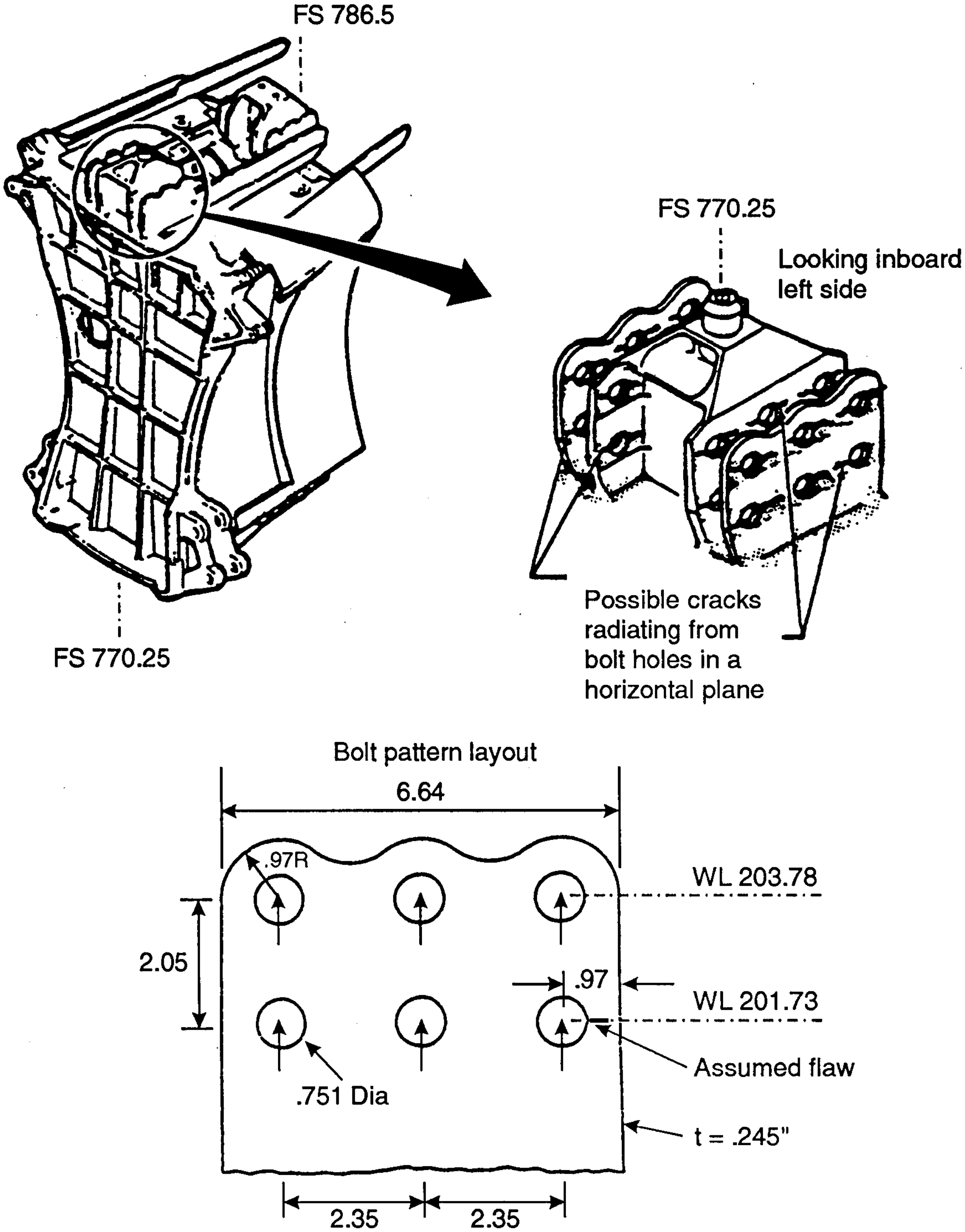


FIGURE A24. DADTA ITEM 41b (FROM REFERENCE 6)

AFDAS Location:	CF3
Channel:	8
SLMP Location:	CF3
Equivalent DADTA Location:	19
Nearby DADTA Location	19a, 19c, 20, 20a, 21

Figures:

A25: SLMP Location CF3 (from reference 5)

A26: SLMP Location CF3 (from reference 5)

A27: DADTA Item 19 (from reference 4)

A28: DADTA Item 19a (from reference 6)

A29: DADTA Item 19c (from reference 6)

A30: DADTA Item 20 (from reference 6)

A31: DADTA Item 20a (from reference 6)

A32: DADTA Item 21 (from reference 6)

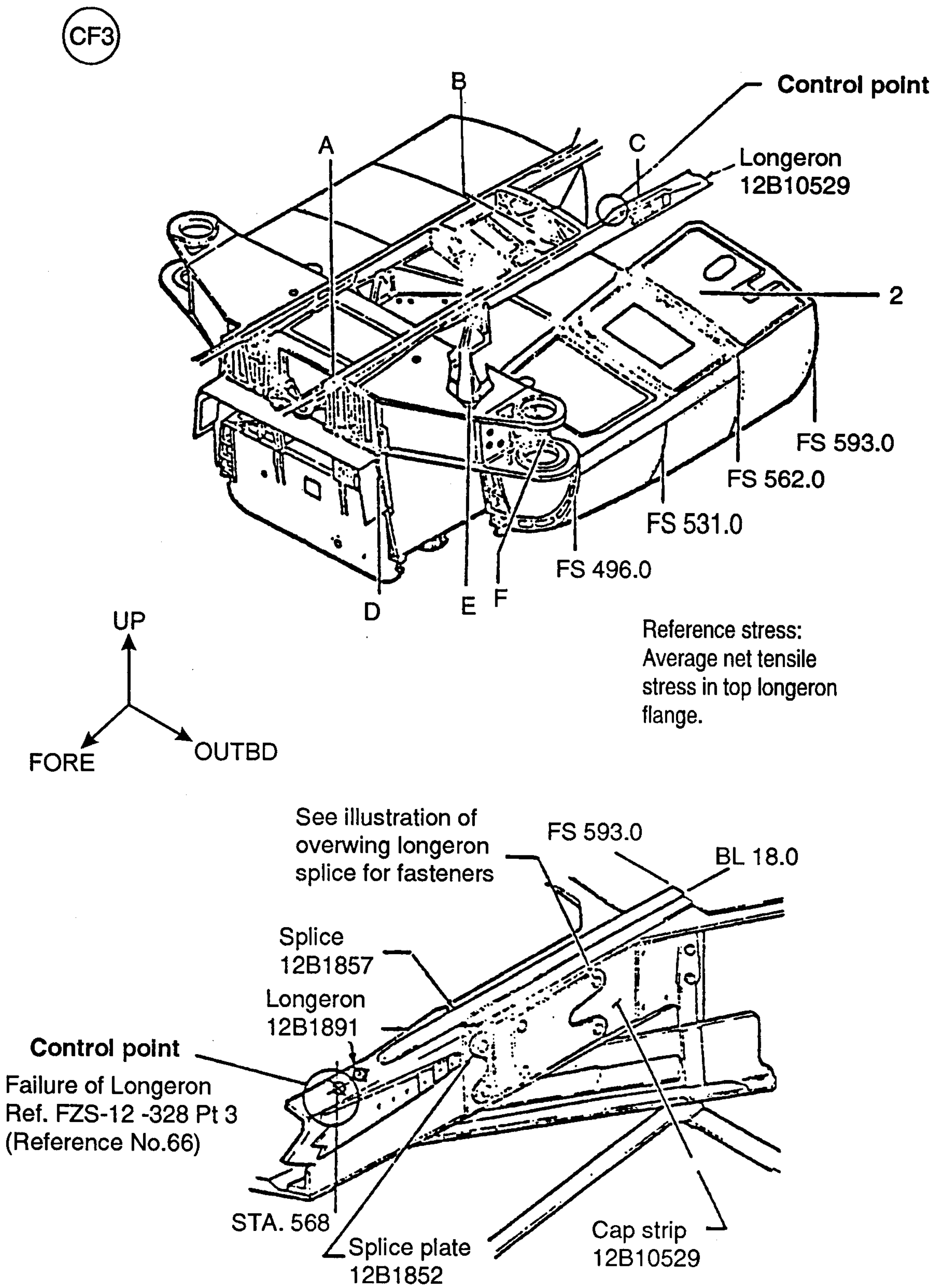
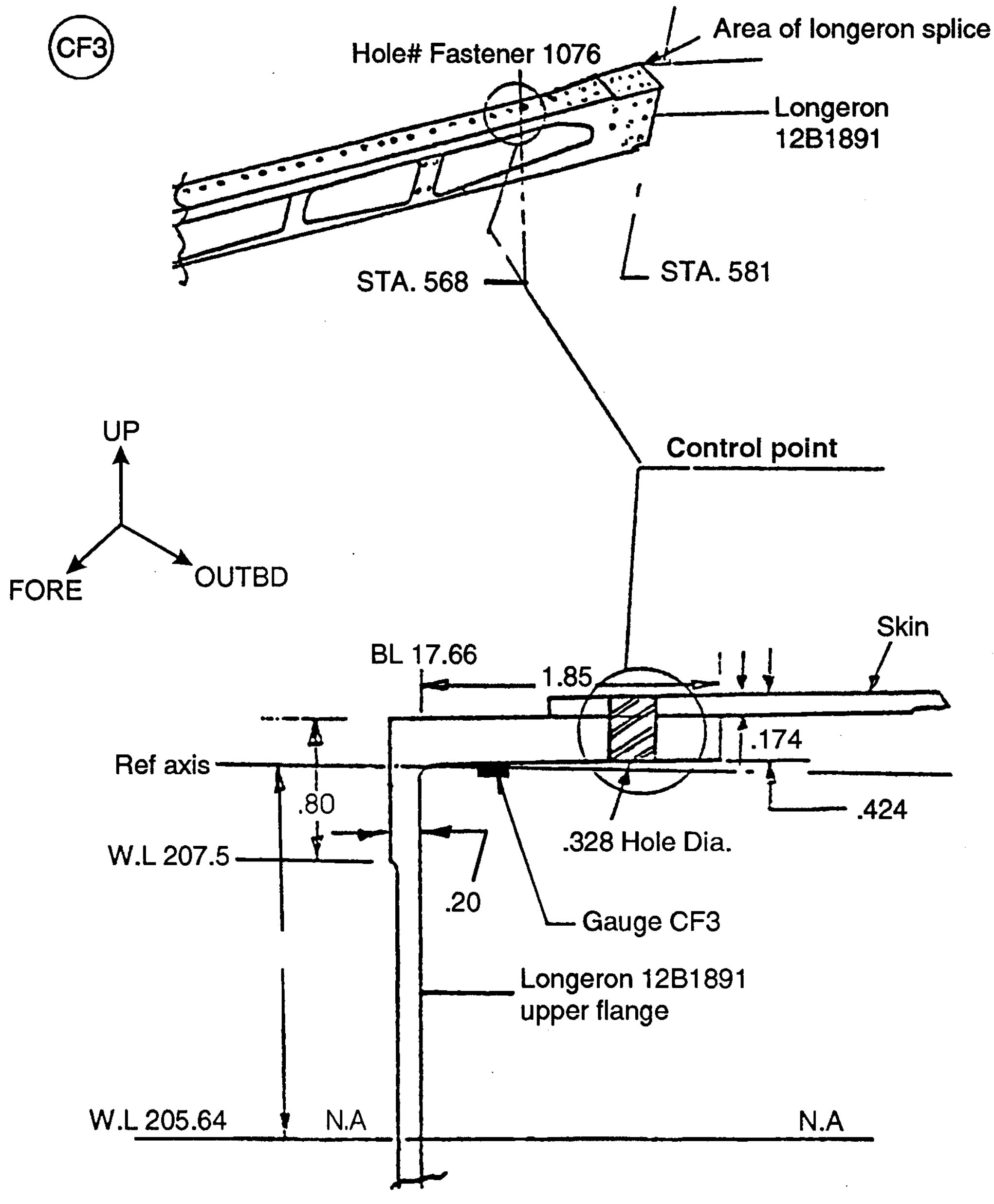


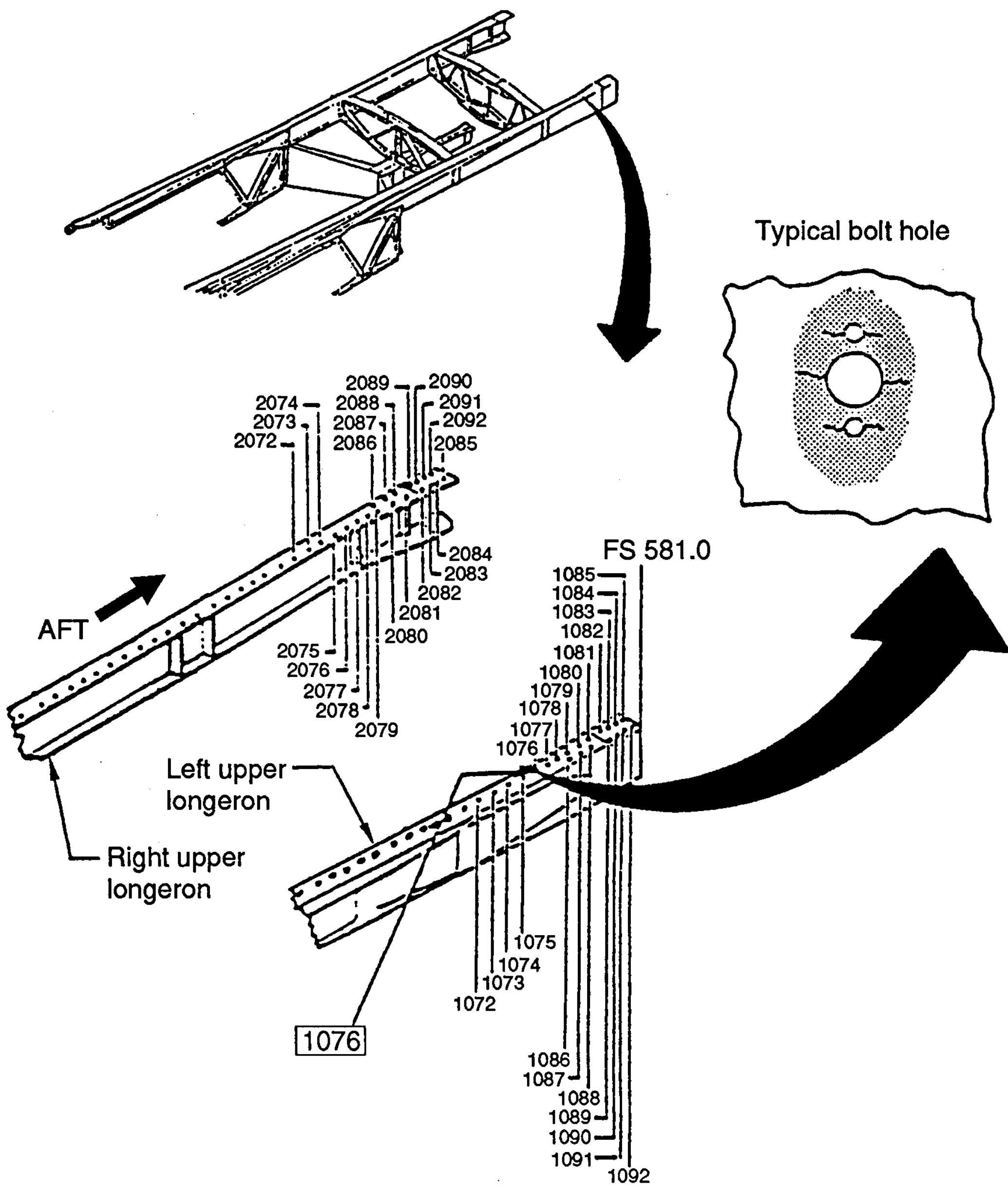
FIGURE A25. SLMP LOCATION CF3 (FROM REFERENCE 5)



NOTE: AFDAS Gauge CF3 is located on the bottom face of the upper flange of the 12B1891 longeron, mid way between holes 1076 and 1077, approximately 0.5" inboard from the vertical web.

FIGURE A26. SLMP LOCATION CF3 (FROM REFERENCE 5)

DADTA ITEM 19



Note: **AFDAS Gauge CF3 is located on the bottom face of the upper flange of the 12B1891 longeron, mid way between holes 1076 and 1077, approximately 0.5" inboard from the vertical web.**

FIGURE A27. DADTA ITEM 19 (FROM REFERENCE 4)

DADTA ITEM 19a
Overwing longeron
Upper flange @ F.S. 531
12B1891

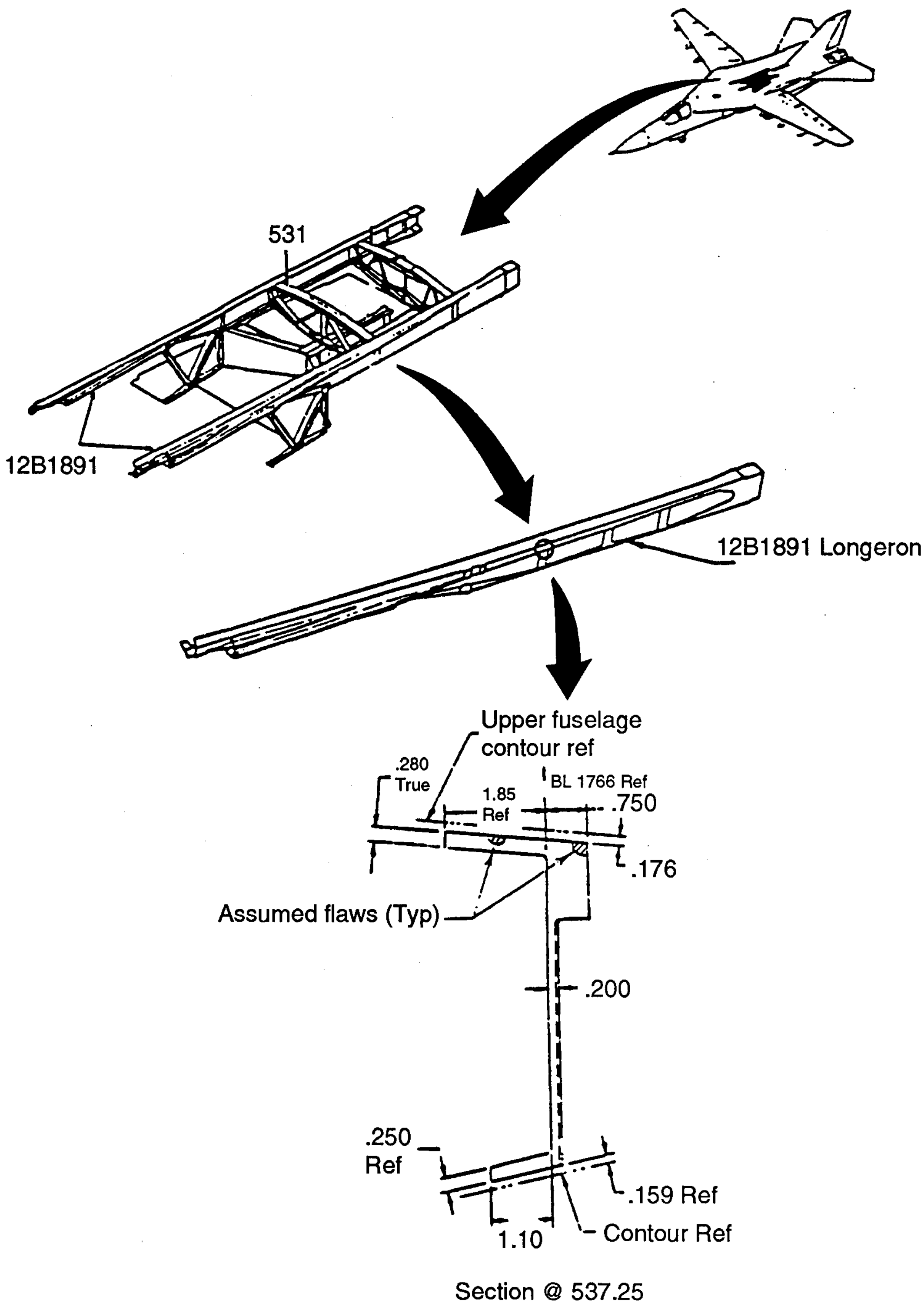


FIGURE A28. DADTA ITEM 19a (FROM REFERENCE 6)

DADTA ITEM 19c
Overwing longeron
Hole in lower flange @ F.S. 532.8
12B1891

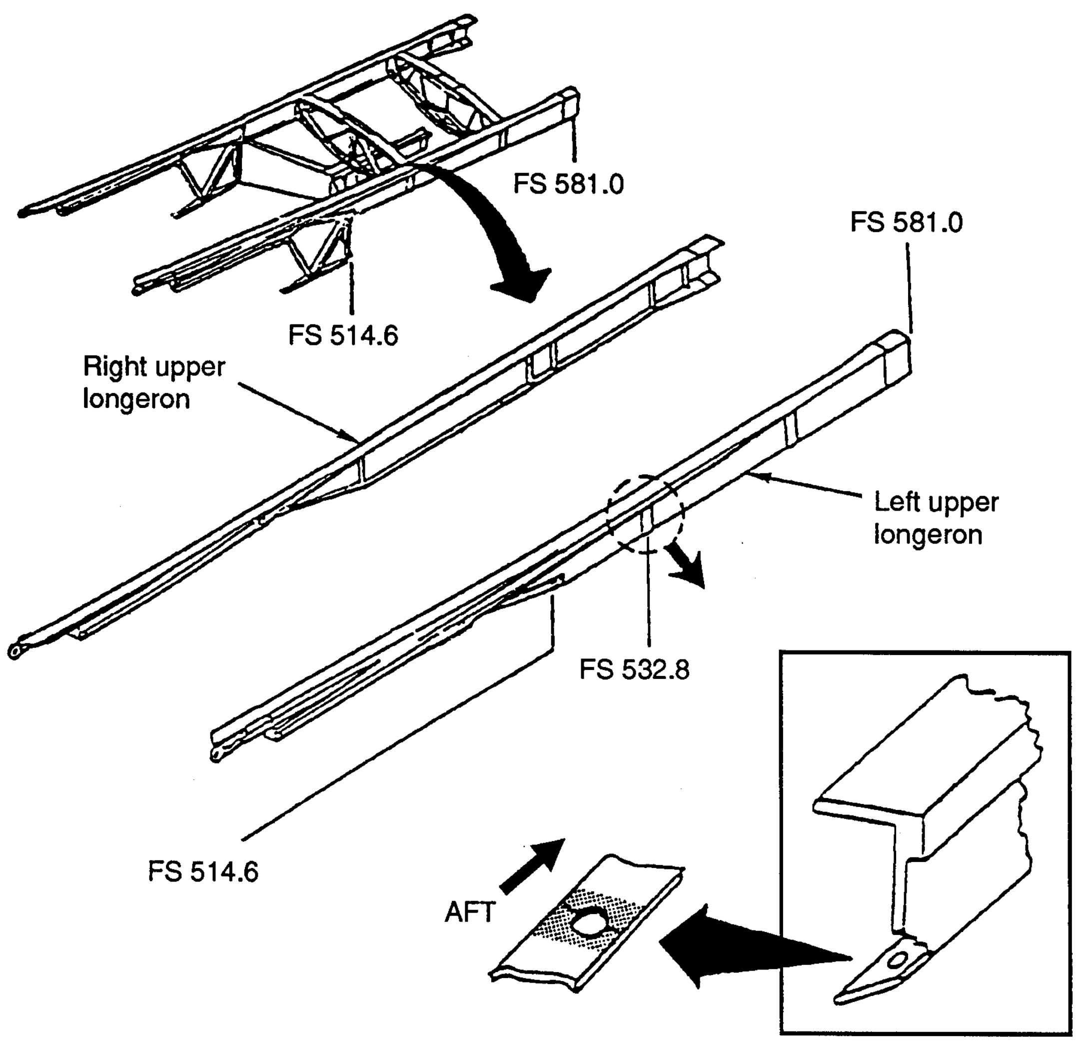


FIGURE A29. DADTA ITEM 19c (FROM REFERENCE 6)

DADTA ITEM 20
Overwing longeron
Hole # 1070 (LHS) and 2070 (RHS) near F.S. 559
12B1891

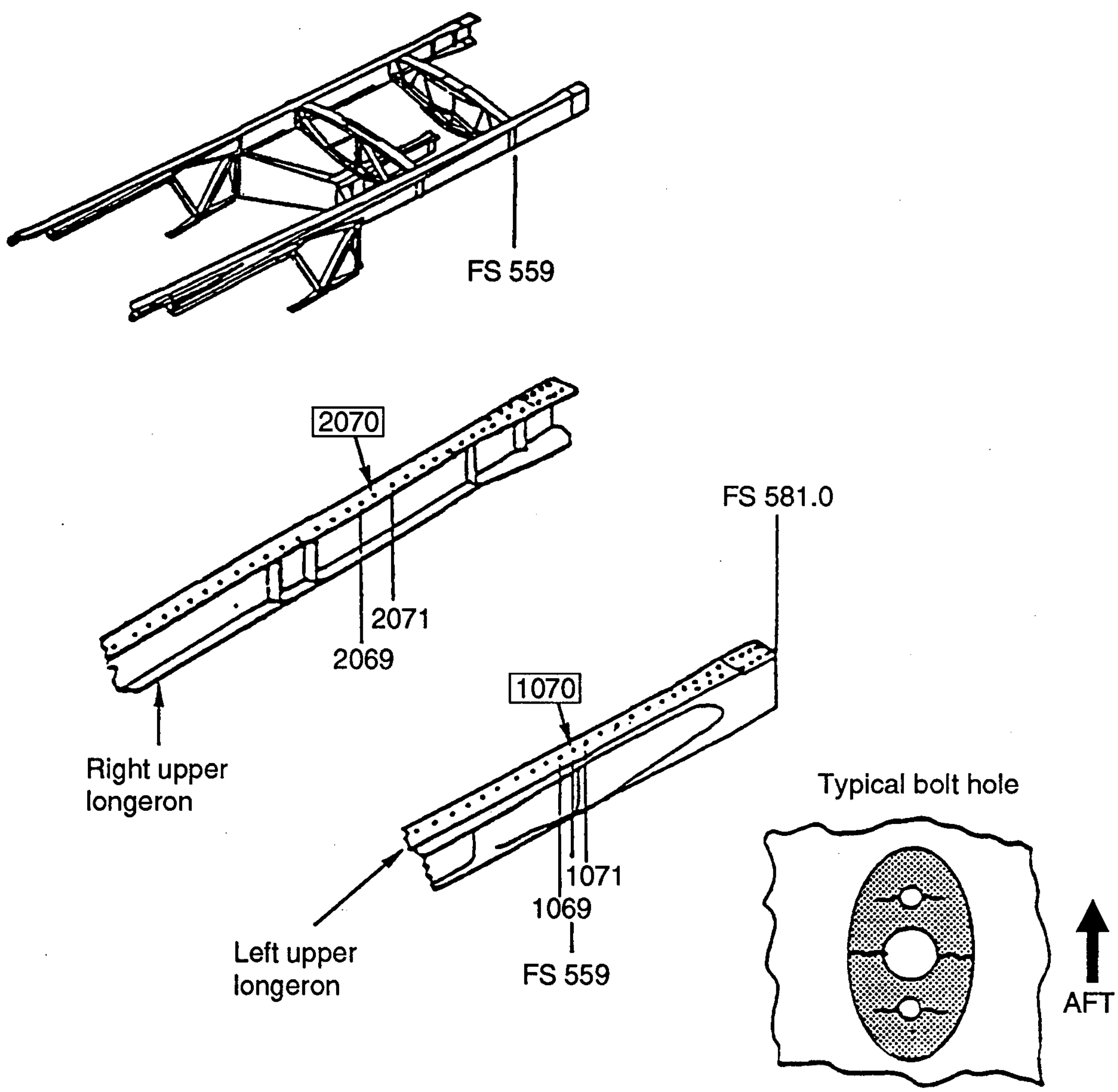


FIGURE A30. DADTA ITEM 20 (FROM REFERENCE 6)

DADTA ITEM 20a
Overwing longeron
Hole # 1054 (LHS) and 2054 (RHS) F.S. 532
12B1891

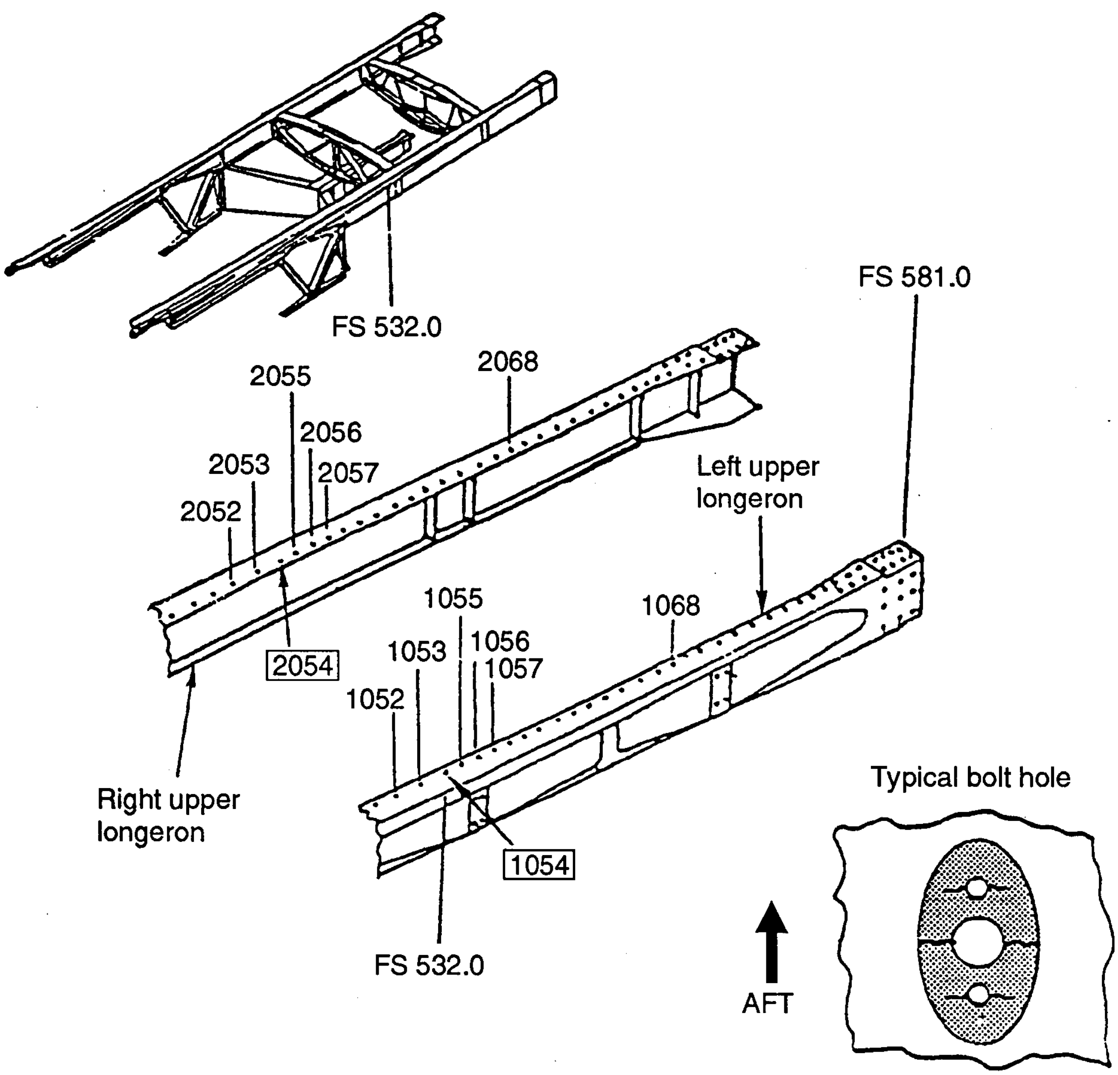


FIGURE A31. DADTA ITEM 20a (FROM REFERENCE 6)

DADTA ITEM 21
Overwing longeron
Fastener hole near F.S. 496
(First 1/2" Dia bolt hole FWD of F.S. 496)
12B1891

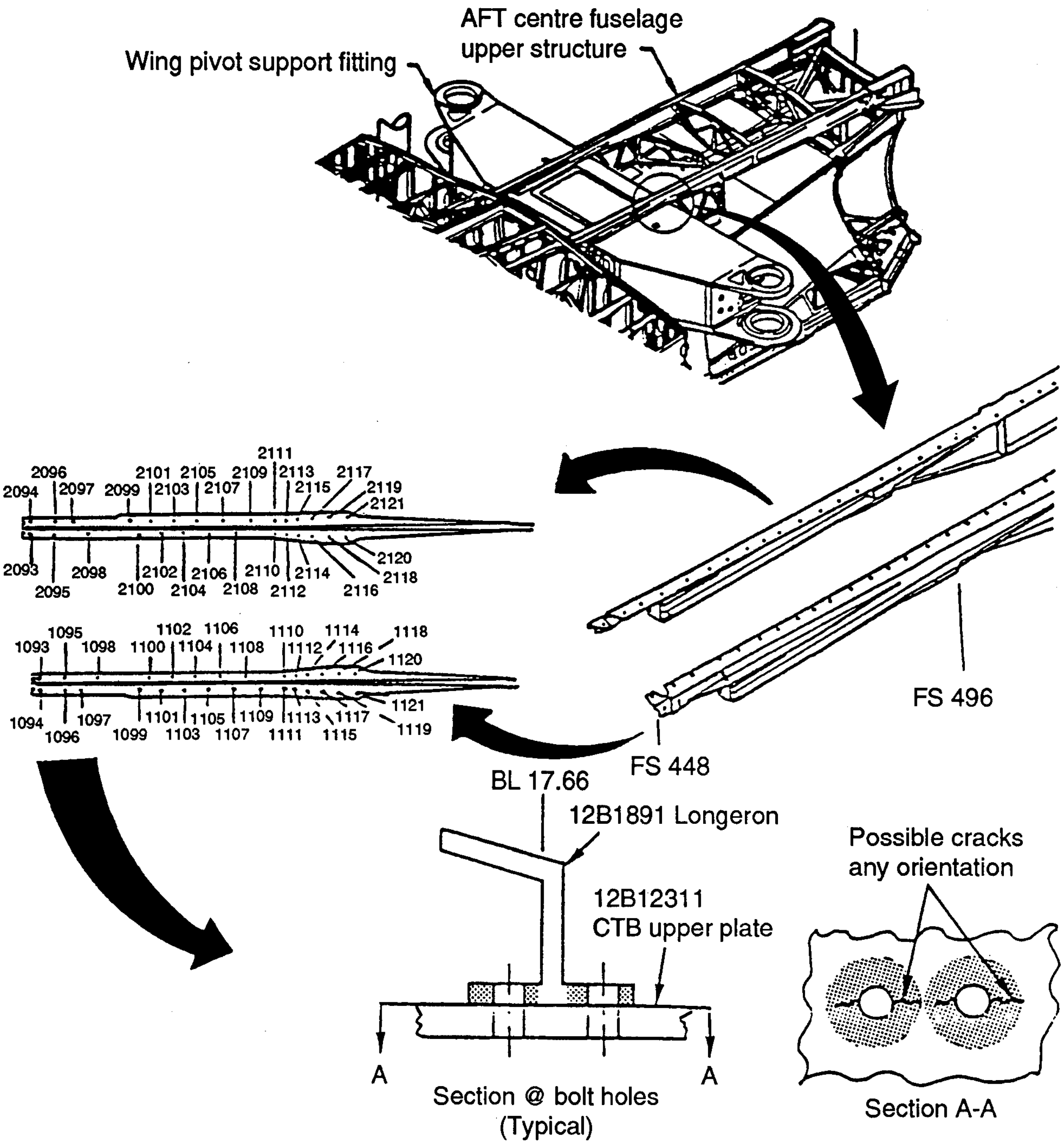


FIGURE A32. DADTA ITEM 21 (FROM REFERENCE 6)

AFDAS Location:	CF5
Channel:	9
SLMP Location:	CF1
Equivalent DADTA Location:	-
Nearby DADTA Location	24a

Figures:

A33: SLMP Location CF1 (from reference 5)

A34: SLMP Location CF1 (from reference 5)

A35: SLMP Location CF1 (from reference 5)

A36: DADTA Item 24a (from reference 4)

Special Comments:

This location appears to have been renamed CF5 from CF1 at some stage. The AFDAS gauge is located adjacent to a hole which is described as hole #253 on the AFDAS drawing (CAC Drawing #EX379040), but appears to be hole #450 according to FZS-12-5018, PAGE 3.7.14. The CF1 control point was to monitor hole #226 originally, but this was deleted in May 1978 and replaced by hole #223. DADTA item 24a refers to hole #226.

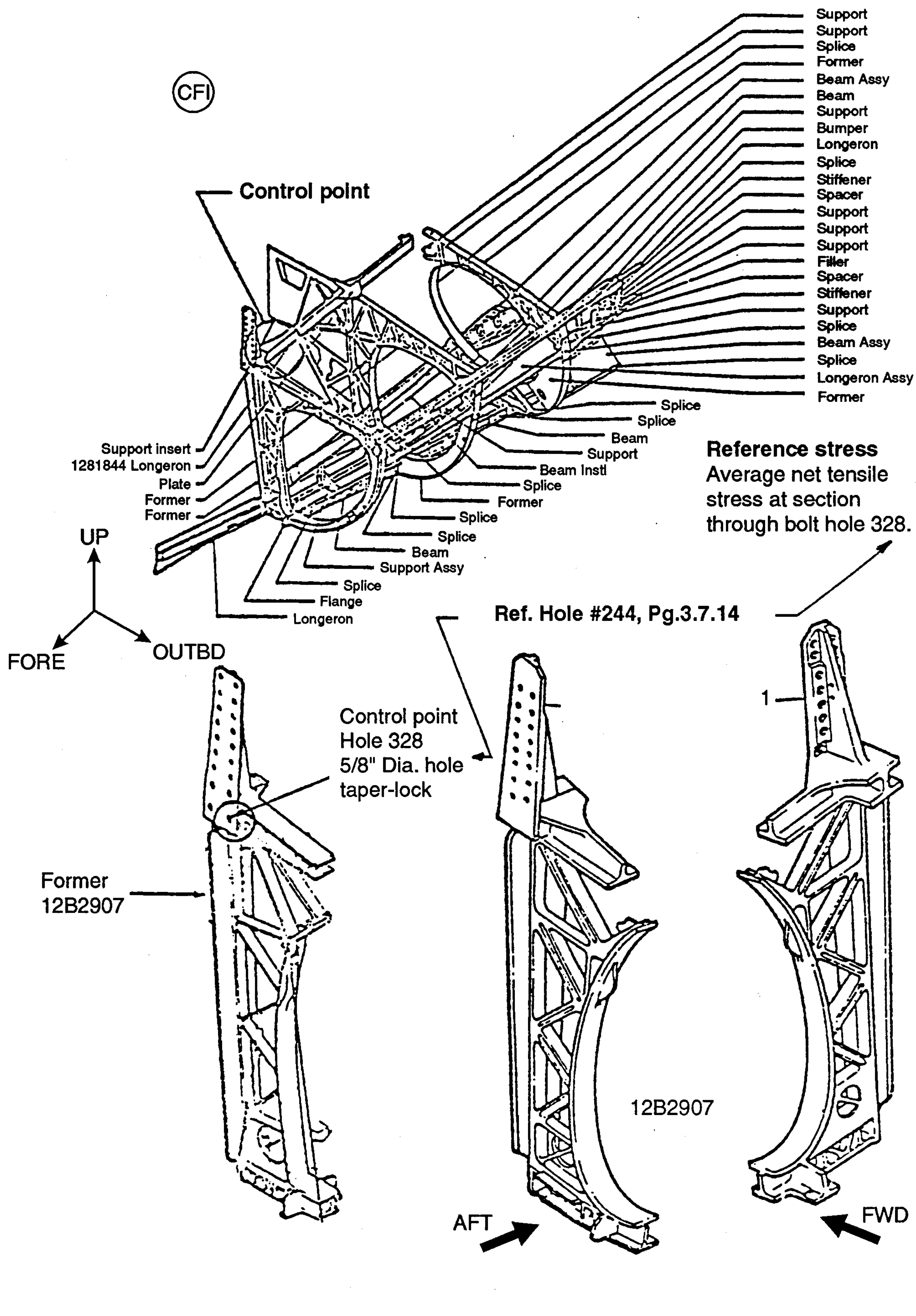
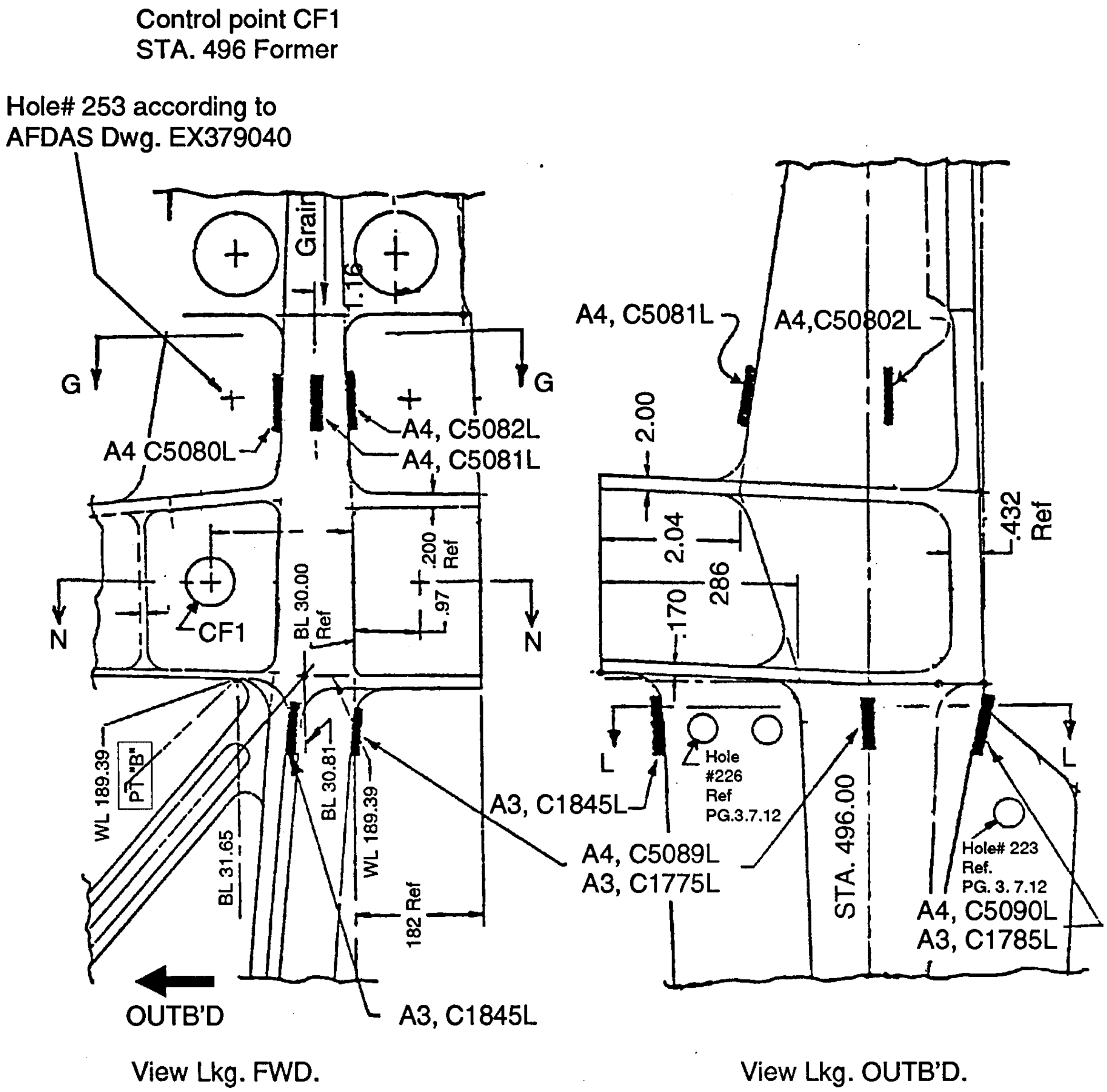


FIGURE A33. SLMP LOCATION CF1 (FROM REFERENCE 5)



NOTE: AFDAS Gauge CF5 is located in an equivalent position to Gauge A4 C5080L, and is approximately 1.6" AFT of the web which attaches to the rear of the WCTB.

FIGURE A34. SLMP LOCATION CF1 (FROM REFERENCE 5)

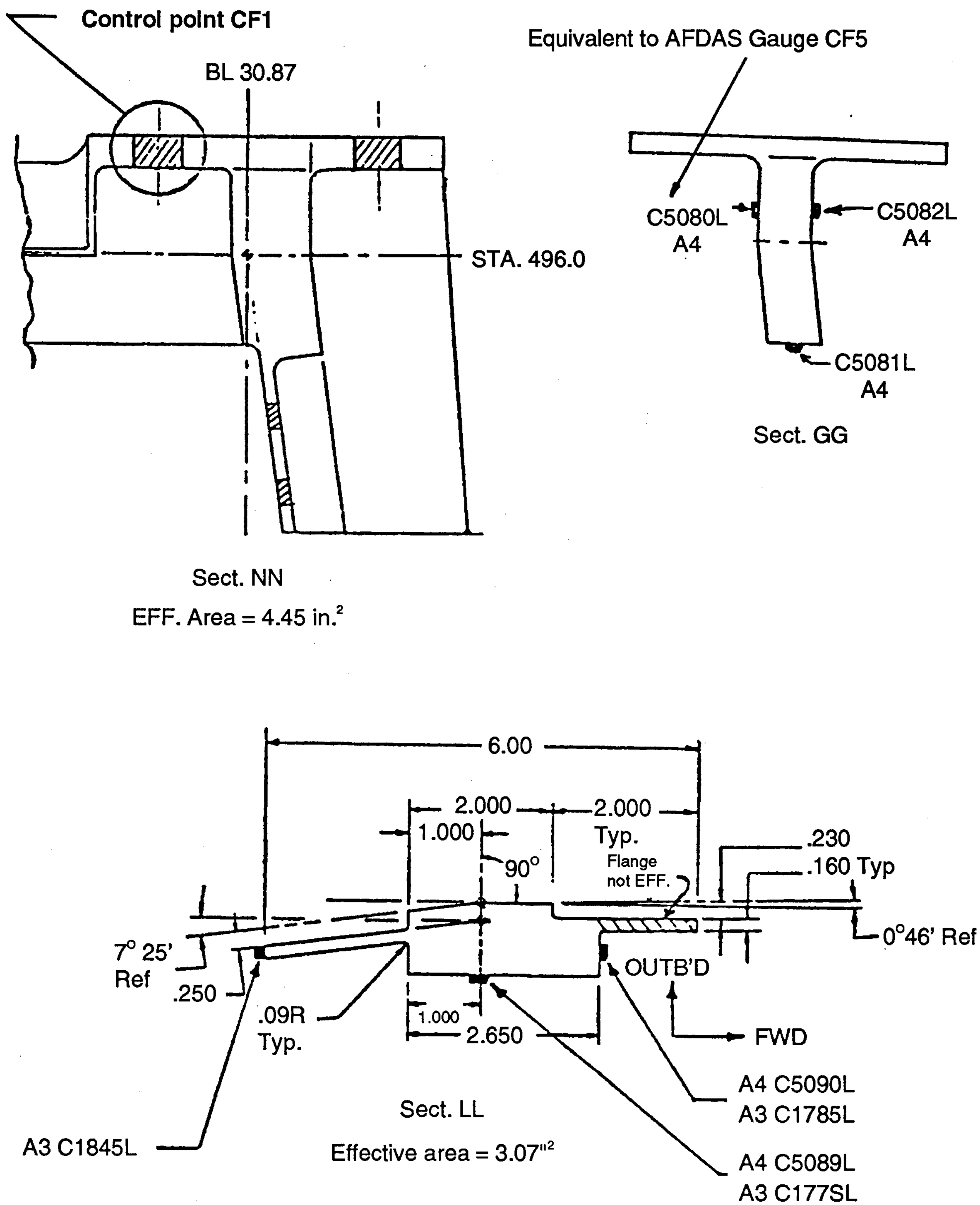


FIGURE A35. SLMP LOCATION CF1 (FROM REFERENCE 5)

DADTA ITEM 24A

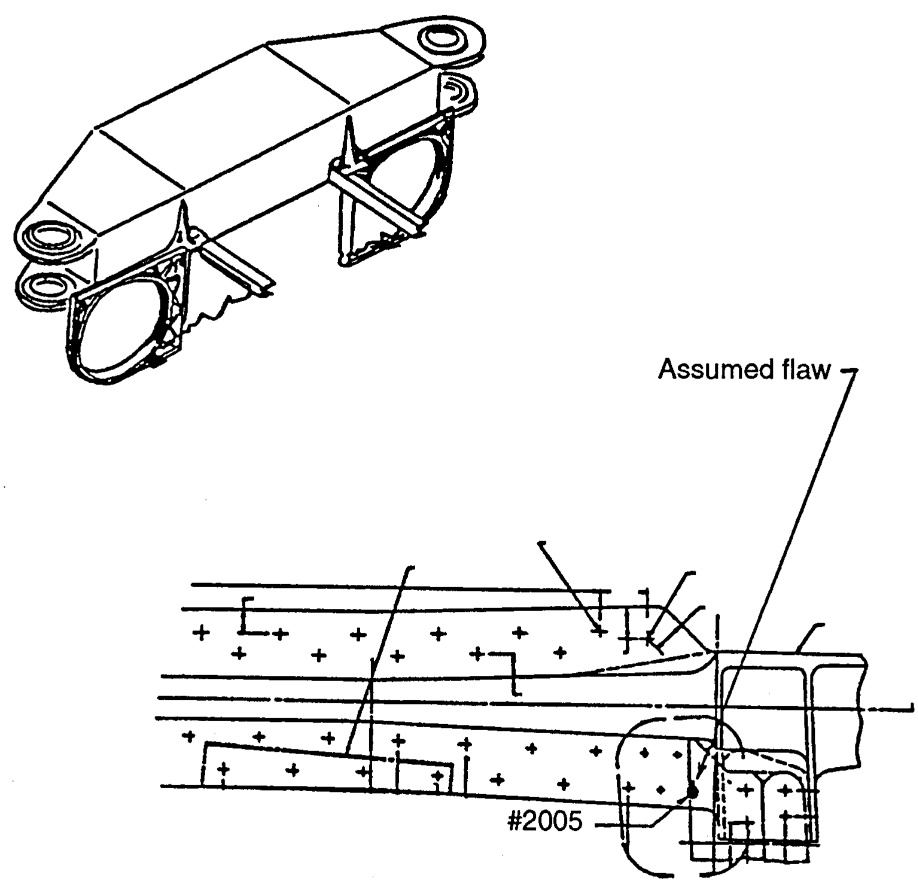


FIGURE A36. DADTA ITEM 24A (FROM REFERENCE 4)

AFDAS Location:	AF2
Channel:	10
SLMP Location:	AF2
Equivalent DADTA Location:	36
Nearby DADTA Location	37a

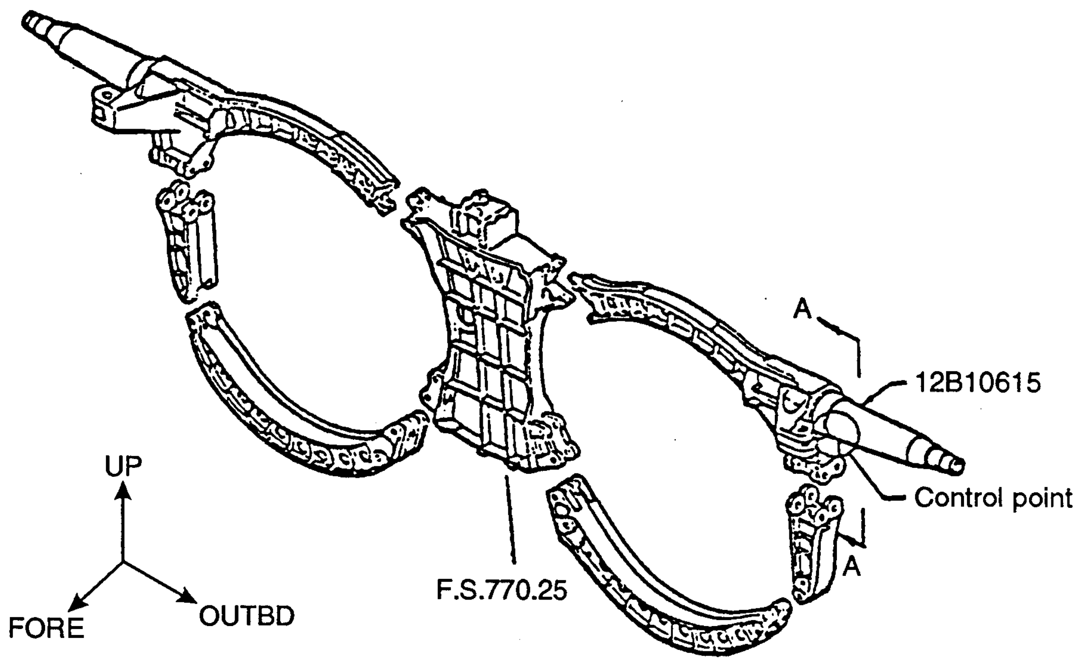
Figures:

A37: SLMP Location AF2 (from reference 5)

A38: DADTA Item 36 (from reference 4)

A39: DADTA Item 37a (from reference 6)

AF2 Bulkhead 770.25 horizontal tail pivot shaft



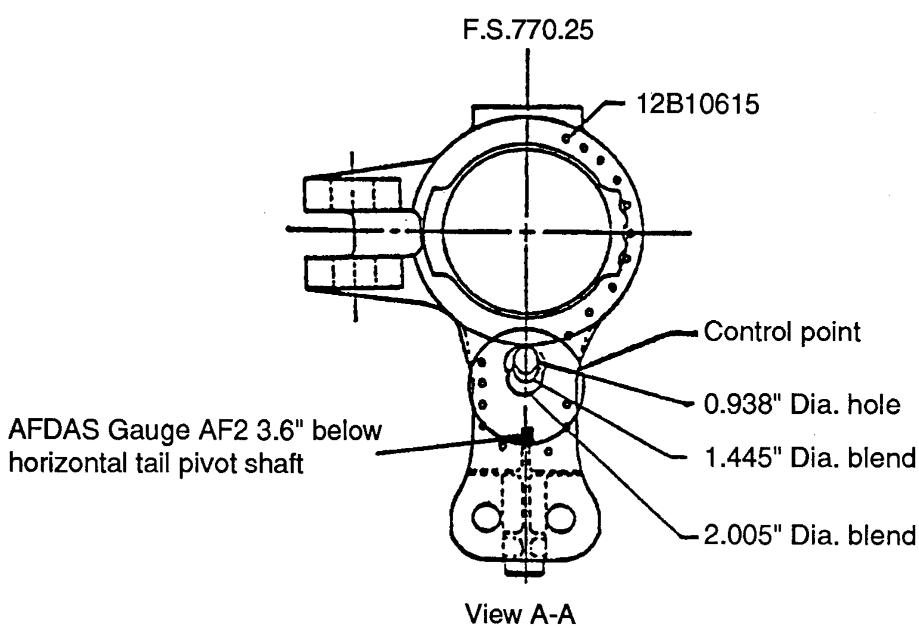
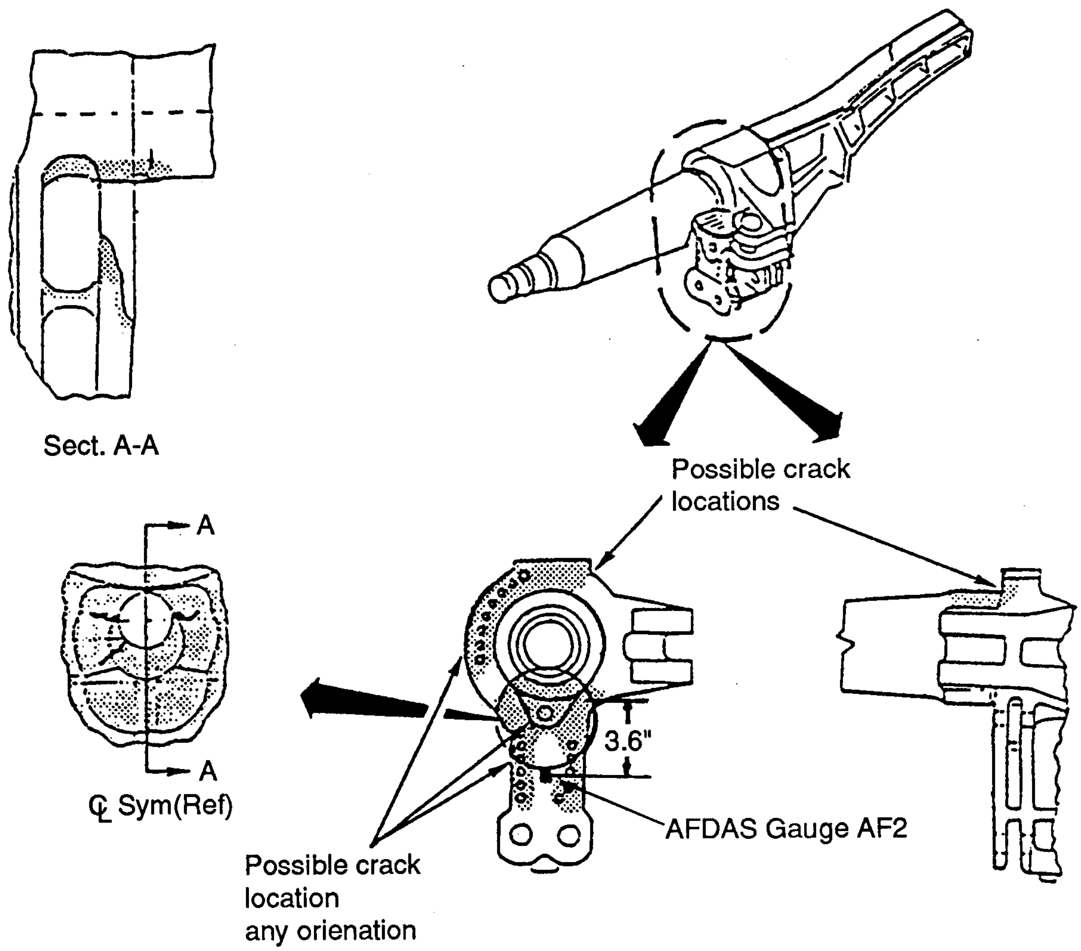


FIGURE A37. SLMP LOCATION AF2 (FROM REFERENCE 5)

DADTA ITEM 36



View looking inboard: upper and lower post base (Right side)

NOTE: AFDAS Gauge AF2 is located approximately 3.6" below the horizontal tail pivot shaft.

FIGURE A38. DADTA ITEM 36 (FROM REFERENCE 4)

DADTA ITEM 37a
Bulkhead assy @ F.S. 770.25
Horizontal tail pivot shaft @ B.L.67.56
12B10521, 12B10615, 12B10809

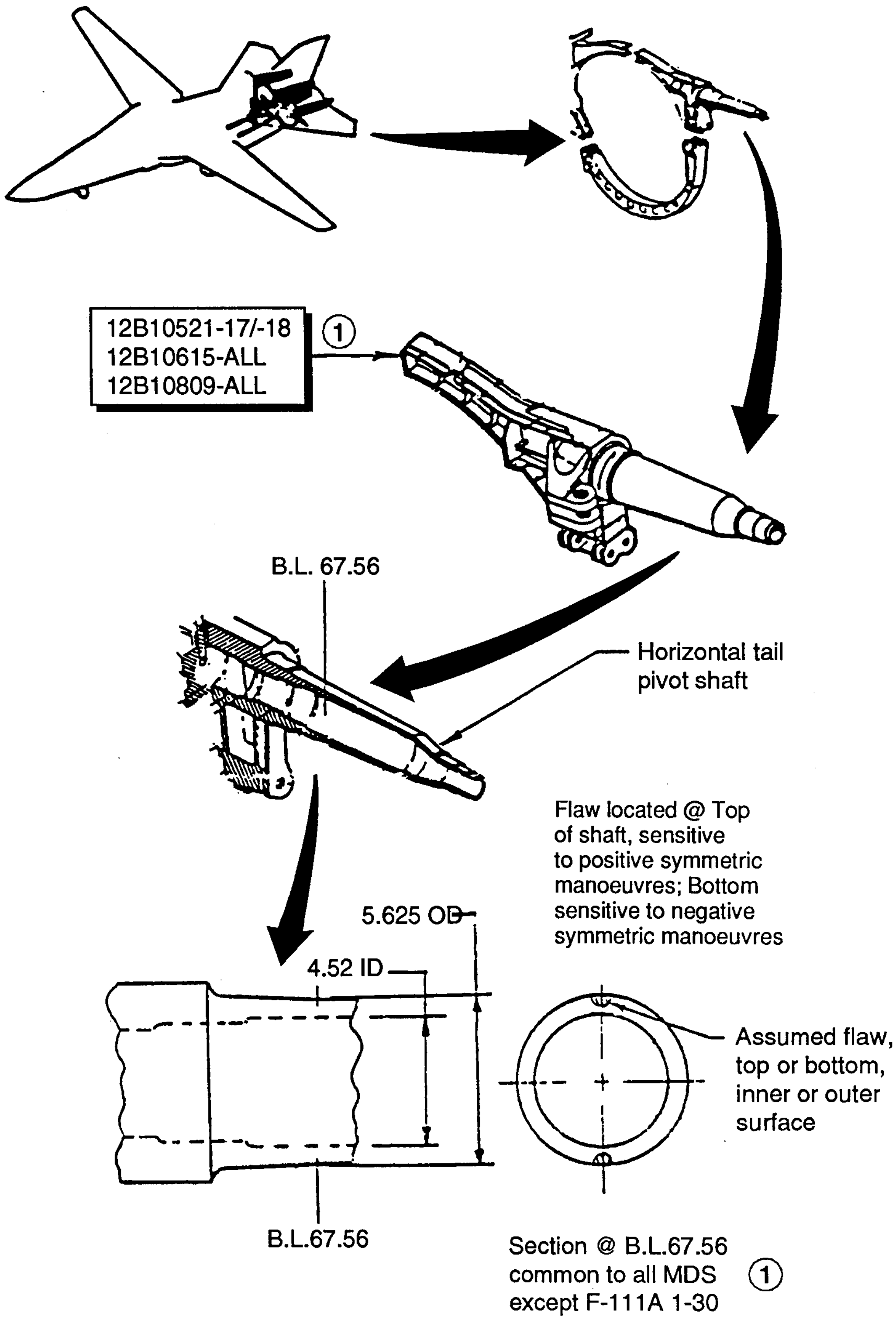


FIGURE A39. DADTA ITEM 37a (FROM REFERENCE 6)

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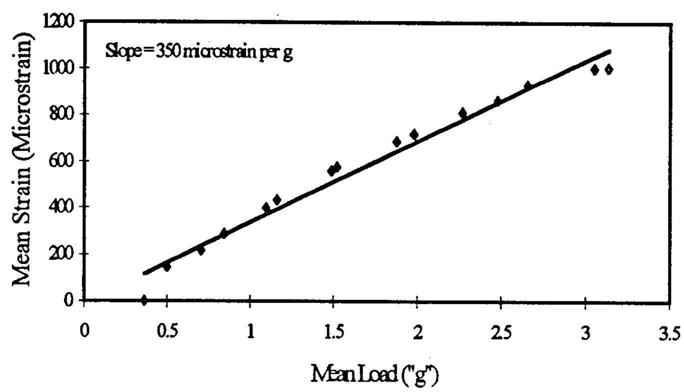
Annex B

Mean, Peak and Trough Calculations

Mean Load "g"	Occurrences	Cumulative Occurrences Mid-point %	Mean Strain "με"	Occurrences	Cumulative Occurrences Mid-point %
-0.075	2	0.85	-1006.3	1	0.56
0.316	3	2.97	-862.5	0	-
0.706	16	11.02	-718.75	0	-
1.097	12	22.88	-575	0	-
1.488	23	37.71	-431.25	1	1.69
1.878	21	56.36	-287.5	0	-
2.269	23	75	-143.75	1	2.81
2.659	10	88.98	0	1	3.93
3.05	6	95.76	143.75	4	6.74
3.441	0	-	287.5	11	15.17
3.831	1	98.73	431.25	7	25.28
4.222	0	-	575	18	39.33
4.613	1	99.58	718.75	21	61.24
-	-	-	862.5	17	82.58
-	-	-	1006.25	7	96.07

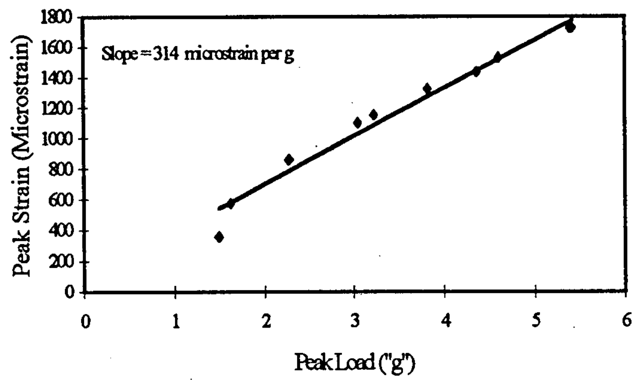
%	Mean Load (g)	Mean Strain (με)
0.85	-0.075	-858.68
1.69	0.0799	-431.25
2.81	0.287	-143.75
2.97	0.316	-123.21
3.93	0.363	0
6.74	0.499	143.75
11.02	0.706	216.73
15.17	0.843	287.5
22.88	1.097	397.13
25.28	1.16	431.25
37.71	1.488	558.43
39.33	1.522	575
56.36	1.878	686.73
61.24	1.98	718.75
75	2.269	811.44
82.58	2.481	862.5
88.98	2.659	930.7
95.76	3.05	1002.95
96.07	3.132	1006.25



Strain versus Load Results, Based on Means Distribution from Reference 3 Data

Load Peak "g"	Occurrences	Cumulative Occurrences Mid-point %	Strain Peak "με"	Occurrences	Cumulative Occurrences Mid-point %
1.488	15	6.36	0	2	1.12
2.269	30	25.42	575	13	9.55
3.05	25	48.73	862.5	16	25.84
3.831	21	68.22	1150	33	53.37
4.613	13	82.63	1437.5	11	78.09
5.394	9	91.95	1725	14	92.13
6.175	5	97.88	-	-	-

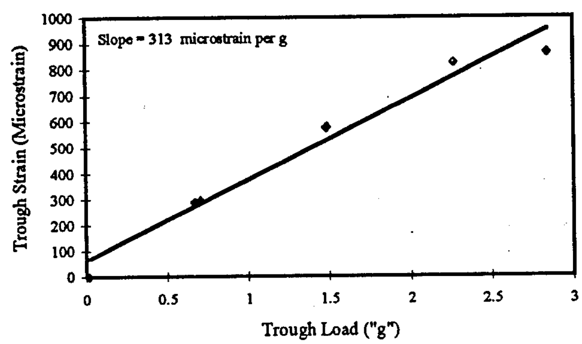
%	Peak Load (g)	Peak Strain (με)
6.36	1.488	357.4
9.55	1.619	575
25.42	2.269	855.1
25.84	2.283	862.5
48.73	3.05	1101.5
53.37	3.236	1150
68.22	3.831	1322.7
78.09	4.367	1437.5
82.63	4.613	1530.5
91.95	5.394	1721.3
92.13	5.418	1725



Strain versus Load Results, Based on Peaks Distribution from Reference 3 Data

Trough Peak "g"	Occurrences	Cumulative Occurrences Mid-point %	Trough Peak "με"	Occurrences	Cumulative Occurrences Mid-point %
-1.638	6	2.54	-1725	1	0.56
-0.856	6	7.63	-575	3	2.81
-0.075	3	11.44	-287.5	7	8.43
0.706	48	33.05	0	3	14.04
1.488	42	71.19	287.5	29	32.02
2.269	10	93.22	575	40	70.79
3.05	1	97.88	862.5	6	96.63
3.831	2	99.15	-	-	-

%	Trough Load (g)	Trough Strain (με)
2.54	-1.638	-713
2.81	-1.597	-575
7.63	-0.856	-328.4
8.43	-0.692	-287.5
11.44	-0.075	-133.2
14.04	0.019	0
32.02	0.669	287.5
33.05	0.706	295.1
70.79	1.48	575
71.19	1.488	579.5
93.22	2.269	824.6
96.63	2.8405	862.5



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K. Walker

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16. ABSTRACT

The Aircraft Fatigue Data Analysis System (AFDAS) is a twelve channel, strain based fatigue data collection and analysis system. The RAAF have recognised that AFDAS offers significant potential improvements over fatigue meters and parametric based systems for the purpose of fatigue monitoring and structural integrity management. It has therefore been implemented on a number of aircraft types, including the F-111.

The system does however require further development and refinement. AMRL was requested by the RAAF to provide assistance and advice on the F-111 AFDAS installation. This report details the progress made so far on the current AMRL F-111 AFDAS support activity. The activity has included aspects which are unique to the F-111 and also some with general applicability to the AFDAS installation on other aircraft types.

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16. ABSTRACT (CONT).

Significant progress has been made in the following areas:

a. Establishing why the strain sensor locations were chosen and how they relate to other locations of importance for fatigue or structural life monitoring reasons.

b. Eliminating operational errors and difficulties which decrease the integrity of the data.

c. Developing new data screening procedures which check the data for inconsistencies and invalid results.

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